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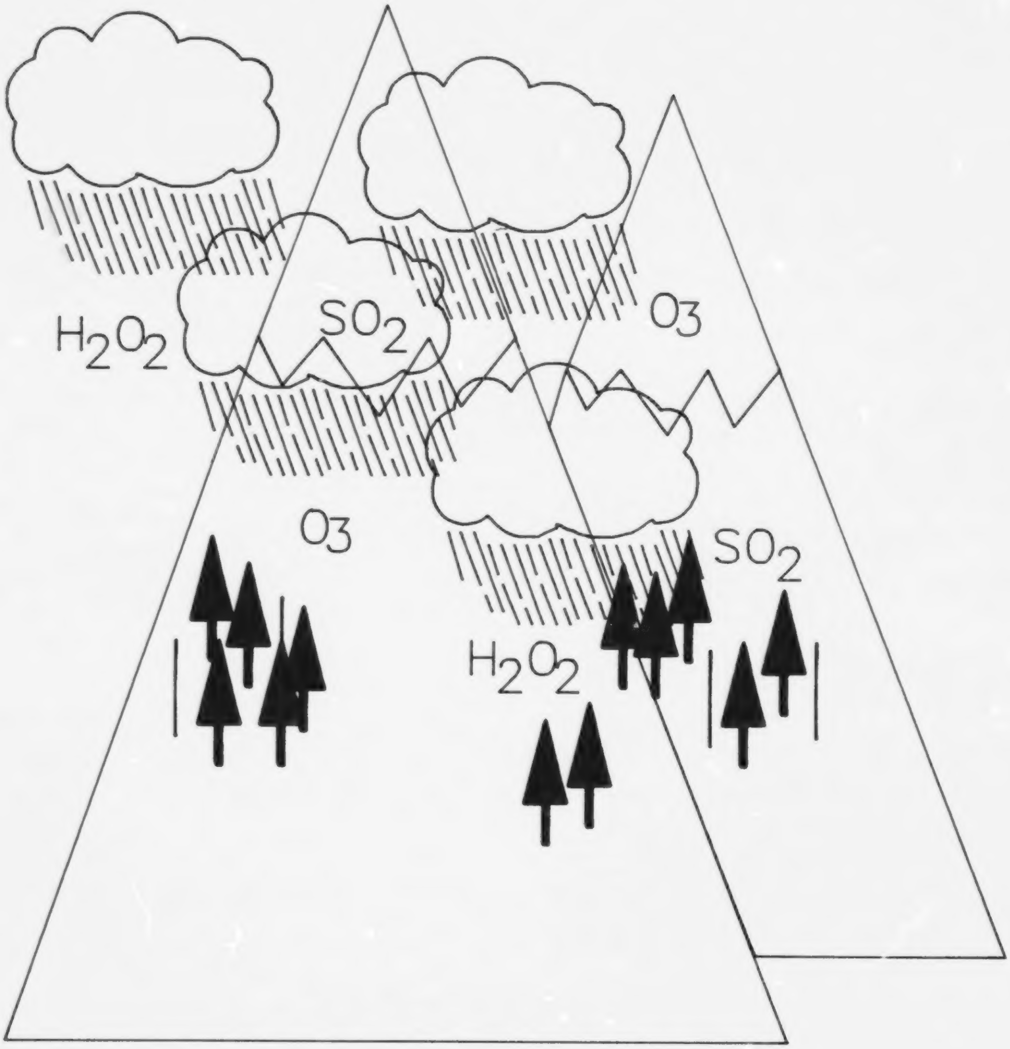

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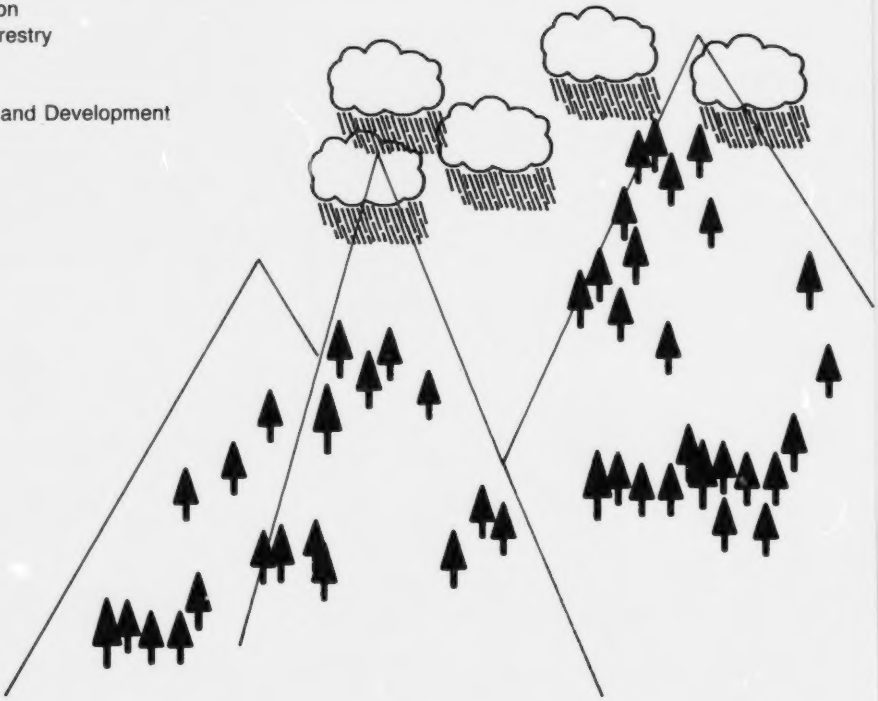

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The Forest Response Program: Atmospheric Deposition Research in U.S. Forests

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Introduction

The possible effects of atmospheric deposition, or "acid rain," on forests is a major environmental issue in the United States as well as other parts of the world. At stake are billions of dollars for pollution controls and possibly the health and long-term productivity of our forests. Approximately one-third of the land area of the United States is forested, providing fiber for timber, paper products, and fuelwood. These forests also provide wildlife habitat, grazing land, recreation and scenic opportunities. Forested watersheds serve as a source for much of the nation's water supply. Determining the effects of acid rain and associated airborne pollutants on U.S. forests will help provide answers to the many questions surrounding this environmental debate.

To address this concern, the Forest Response Research Program was established as a major component of an interagency effort designed to provide the scientific basis for answering questions about acid rain. The effort was authorized by the U.S. Congress in 1980 with the passage of the Acid Precipitation Act (Title VII of the Energy Security Act, PL 96-294), which established the Interagency Task Force on Acid Precipitation. The Task Force provided the foundation for the National Acid Precipitation Assessment Program (NAPAP). The goal of NAPAP is to develop and improve an objective, comprehensive information base on the causes and effects of acid deposition. The program includes research, monitoring, and assessment activities that emphasize the timely development of a firmer scientific basis for decision making by legislators, regulatory officials, resource managers, private sector decision makers, environmental groups, and the public. NAPAP has interrelated projects in several research categories including natural pollutant sources, human-caused pollutant sources, atmospheric processes, deposition monitoring, aquatic effects, terrestrial effects, effects on materials, and control technologies.

NAPAP has assigned a high priority to research designed to determine if U.S. forests are being affected by airborne pollutants. Specific goals of the NAPAP forestry research program are to:

1. Determine effects on productivity and health of major tree species from exposure of foilage to near ambient levels of acidic deposition, gaseous sulfur dioxide, nitrogen oxides, and associated oxidants (foliar-mediated effects).
2. Estimate long-term effects on productivity and forest health from acidic deposition on a wide variety of forest soils at near ambient levels (soil-mediated effects).
3. Identify major factors causing visible damage to forests above cloudbase in the high mountains of the eastern United States.
4. Initiate biochemical, physiological, and ecological research to study whether causal relationships exist between acidic deposition and related pollutants and forest conditions where adverse changes are demonstrable (mid- to long-term mechanistic studies).
5. Establish a program for the continued documentation and detection of new changes in forest condition (long-term monitoring).

Background

In 1984 the USDA Forest Service, the U.S. Environmental Protection Agency (EPA), and forest industry (through NCASI--the National Council of the Paper Industry for Air and Stream Improvement) jointly began planning, managing, and funding an intensive research program on the effects of atmospheric deposition on U.S. forests. This "Forest Response Program" is designed to provide answers to important environmental policy questions now facing regulators and public decision makers about pollutant emissions in the United States. The program is an integral part of the NAPAP terrestrial effects research effort.

Research is conducted by a number of "research cooperatives." Each cooperative is a multi-institution, multi-disciplinary team of investigators studying the effects of atmospheric deposition on a broad forest region. The research program includes controlled laboratoray studies, intensive field investigations (both controlled and uncontrolled), and modeling of effects on growth and yield. Almost all research in the program is funded on a competitive basis.

Cooperatives have been specified for four forest regions--eastern spruce-fir, southern commercial forests (primarily pines), eastern hardwoods, and western conifers. Other program components include the National Vegetation Survey, the Atmospheric Exposure Cooperative, and the Quality Assurance and data Synthesis and Integration Projects.

Eastern Spruce-Fir Research Cooperative

Aside from the photo-oxidant effects documented in the mixed conifer forest near the Los Angeles basin in California, the only significant, visible decline in U.S. forests possibly caused by regional air pollution (acidic deposition and/or associated air pollutants) is seen in the high-elevation spruce-fir forests of the Appalachian mountains. The objectives of the Spruce-Fir Research Cooperative are to determine why spruce are declining at high elevations and to determine the effects of acidic deposition and associated air borne pollutants on spruce-fir forests. This cooperative is managed by the USDA Forest Service, Northeastern Forest Experiment Station, Broomall, Pennsylvania.

Southern Commercial Forest Research Cooperative

The most important commercial forests in the United States are the pine plantations and mixed pine/hardwood natural forests of the coastal plain and piedmont regions stretching from Virginia to Texas. Although no significant visible damage or mortality has been observed beyond what can be ascribed to natural causes, there are observations suggesting a decline in forest productivity in certain areas. The objective of the Southern Commercial Forest Cooperative is to determine if, when, where, and to what extent acidic substances and associated airborne contaminants are causing, or could cause, beneficial or detrimental changes to commercial forests in the southern and southeastern United States. The cooperative is managed by the USDA Forest Service, Southeastern Forest Experiment Station, Asheville, North Carolina.

Eastern Hardwoods Forest Research Cooperative

A large portion of the forested area in the eastern United States is covered by hardwoods. Periodic declines of various hardwood species have been observed on a regional scale, but generally have been associated with disease and/or insect epidemics. In recent years sugar maple forests (particularly sugar bushes) have declined in the northern States and Canada's eastern provinces; the cause is still unknown. The present objective of the Eastern Hardwoods Cooperative is to better define the current condition of eastern hardwood forests, and to evaluate whether there is a relationship between forest condition and atmospheric deposition. The results of such work will provide a better foundation to initiate longer-term research in the eastern hardwood forest types. The cooperative is managed by the USDA Forest Service, Northeastern Forest Experiment Station, Broomall, Pennsylvania.

Western Conifer Forest Research Cooperative

With the exception of forests in the San Bernardino Mountains northeast of Los Angeles, regional-scale exposure of western forests to acidic deposition and associated airborne pollutants is thought to be much less significant than in the eastern United States. Their high commercial and recreational value, however, calls for exploratory investigations to clearly determine if western forests are at risk from airborne pollutants. The objectives of the Western Conifer Research Cooperative are to determine 1) to what extent western forests have suffered damage; 2) what role, if any, atmospheric deposition and related airborne pollutants have played in causing any damage; and 3) the potential for future deposition-induced decline of western forests. The cooperative is managed by the EPA Environmental Research Laboratory, Corvallis, Oregon.

National Vegetation Survey

The National Vegetation Survey was developed to support work done by the research cooperatives and to design and implement a long-term forest health survey. The objectives of the Vegetation Survey are to: 1) determine if there is any current or past relationship between measurement trends for forest condition and atmospheric deposition; 2) determine if there is any spatial relationship between observed forest condition and patterns of atmospheric deposition; and 3) develop a database to assist in assessment of alternative emission control strategies and contribute to other research on the cause/effect relationships between forest condition and atmospheric deposition. The National Vegetation Survey is managed by the USDA Forest Service Southeastern Forest Experiment Station, Asheville, North Carolina.

Atmospheric Exposure Cooperative

The Atmospheric Exposure Cooperative is another support effort whose function is to monitor the exposure of forests to airborne chemicals and provide estimates of regional chemical deposition. Deposition and meteorological monitoring is done at all Forest Response Program intensive field research sites. Detailed monitoring of components and concentrations of atmospheric deposition at field research sites is an important part of the Forest Response Program. This monitoring support is managed by the EPA Atmospheric Sciences Research Laboratory, Research Triangle Park, North Carolina.

Synthesis and Integration-Quality Assurance

A certain amount of program-wide planning and review, centralized data management, and information exchange is accomplished by two additional program components. The Synthesis and Integration Project combines individual project and cooperative-level results to provide quantitative estimates of forest response to acidic deposition and associated airborne pollutants. The project has the long-term goal of estimating forest responses under varying pollutant burdens. The Quality Assurance (QA) Project provides guidance and assistance to investigators for implementing a quality assurance program that assures comparability of data across sites and over time. This is done primarily through standardization and monitoring of ongoing research to assure compliance with approved protocols. The QA program also provides evidence of data quality through qualitative and quantitative evaluations of the research activities. These program components are located at the EPA Environmental Research Laboratory, Corvallis, Oregon.

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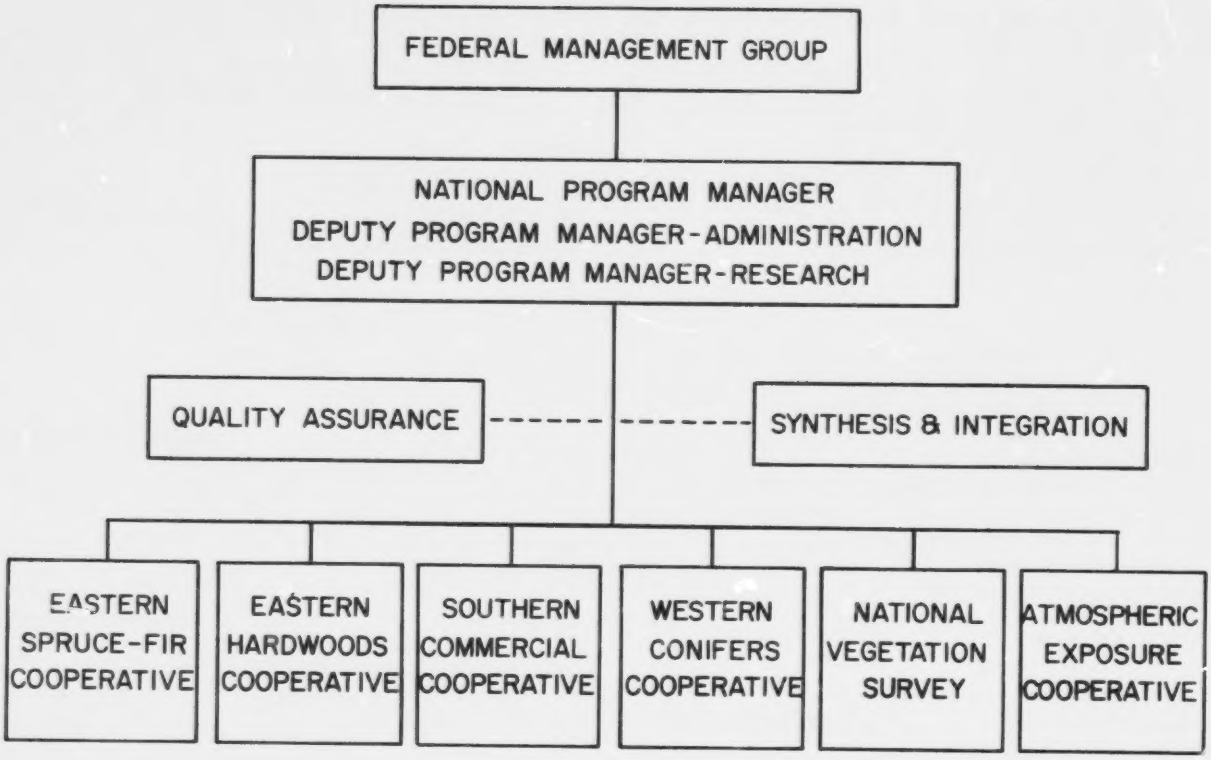
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ATMOSPHERIC EXPOSURE COOPERATIVE

Figure 1.--Management structure of the Forest Response Program.

Research Planning for the Spruce-Fir Research Cooperative

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Abstract

The research planning activities within the Spruce-Fir Research Cooperative were initiated shortly after its creation through a series of workshops involving research scientists, resource managers and policy makers. This effort resulted in a conceptual model which synthesized the current scientific knowledge on red spruce. In addition, a set of hypotheses of cause which were believed to be worthy of research was developed and a research strategy to study them was outlined.

Introduction

The recent evidence of growth decline and mortality of red spruce-fir forests in the eastern United States has captured public concern. Research conducted in the high-elevation forests of the northern Appalachians indicates drastic declines (Johnson et al. and Bruck et al., this proceedings). Vogelmann et al. (1985) documents density, biomass, and regeneration declines for red spruce (*Picea rubens* Sarg.) on Camels Hump, VT over the past two decades with an associated decrease in balsam fir (*Abies balsamea* (L.) Mill.) biomass. Similarly, Scott et al. (1984) notes a 60-70 percent reduction in red spruce basal area and an 80 percent decrease in seedling frequency at high elevations on Whiteface Mountain, NY. In a broader geographical study, Federer et al. (this proceedings) examined red spruce and balsam fir growth decline via increment core samples taken from trees located primarily in low elevation forests of New England. Their results indicate that red spruce basal area increment has declined 13-40 percent since the peak in 1960. This trend is independent over size and age classes and the decline is independent of elevation. Although balsam fir was seen to decrease by 7-37 percent in basal area increment from its peak in 1970, analysis revealed an age trend which indicates possible correlation with natural aging processes. Research in the southern Appalachian Mountains by Bruck (1984) reveals declines in red spruce on Mt. Mitchell, NC, while in the mid-Appalachian forests of Virginia and West Virginia, Adams et al. (1985) show radial growth declines for red spruce, and Fraser fir (*Abies fraser* (Parsh)) over the last two decades.

For more than a decade, research has been directed toward the possible role of atmospheric deposition in forest dieback and growth declines. Although numerous hypotheses have been proposed, most of the research relating atmospheric deposition to stresses of spruce-fir forests has been fragmentary, limited in scope, and inadequate in developing a comprehensive, scientifically based explanation of the effect of long-term exposure to atmospheric deposition (SAF 1984). This is due to the complexity of extrapolating theoretical and experimental results to field situations (Johnson and Siccama 1984) since:

1. Experimental work has been focused on a single stress and its effect on a few responses, but in the field, trees are under numerous stresses which may act synergistically, yielding results differing from the experimental research;
2. Field studies have revealed nutritional and physiological differences between affected and unaffected trees, but it is difficult to determine if the differences are a cause or an effect of the disease;
3. Little baseline data exist prior to 1960 in which recent soil and vegetation characteristics can be compared to assess what ecosystem changes may have occurred; and
4. Many symptoms appear to be the result of secondary agents and the site or nature of the original stress may be obscured.

Hence, the determination of the role of atmospheric deposition in the recent decline of red spruce-fir forests will be difficult.

In recognition of the concern about the decline in growth, yield and vigor of forest resources, the interagency National Acid Precipitation Assessment Program (NAPAP) has organized the Forest Response Program (FRP) which consists of six cooperatives to assess the effects of atmospheric deposition on forest resources. The FRP is a joint effort between the USDA Forest Service and the U.S. Environmental Protection Agency. Specifically, the FRP address three policy questions:

(1) Is there a significant problem of forest damage in North America which might be caused by acid rain, alone or in combination with other pollutants?

(2) If so, what is the causal relationship between acid rain deposition, alone or in combination with other pollutants and forest damage in North America?

(3) If there is a causal relationship, what is the dose-response relationship between acid deposition, alone or in combination with other pollutants and forest damage in North America?

The Spruce-fir Research Cooperative (SFRC) was initiated in 1985 to specifically address the above policy questions for the red spruce-fir forests in the eastern United States. The Northeastern Forest Experiment Station was assigned the responsibility of coordinating these research activities.

A.E.A. Planning Project

Since the possible causes for spruce decline are many, research scientists, managers, and policy makers have different perceptions of the current spruce decline situation and concerns about the possible effects of atmospheric pollutants on spruce-fir forests. They also have different perspectives on appropriate research approaches and methods for addressing these issues. In recognition of the various causes and perceptions of spruce-fir decline, the SFRC decided to conduct research that both reflects the best current understanding of spruce decline and atmospheric pollutant effects on spruce-fir forests while promoting consensus among scientific, management and policy communities. Thus, the goal was to develop a set of rational, defensible research recommendations from the combined expertise and perspectives of research scientists, managers, and policy makers. The specific objectives of the project were to:

1. Develop a rational, defensible research program for assessing and understanding the effects of atmospheric deposition on the spruce-fir forests of the eastern United States,
2. Develop a common understanding of the state of knowledge of spruce-fir decline and the possible role of atmospheric deposition, and
3. Develop a prototype model of atmospheric deposition effects on spruce-fir forests.

Background

The concept of a hypothesis of cause is fundamental to the methods used in this project. Simply stated, a hypothesis of cause is a statement that links a potential source of tree stress (natural or anthropogenic) to its hypothesized effects on forests via physical, chemical and biological processes. Collectively, a set of hypotheses of cause reflects the best current understanding of the causal mechanisms by which stresses may influence forests.

The development of the research recommendations described in this report was accomplished by proceeding through the following steps:

1. Development of a model of natural and anthropogenic influences on spruce-fir forests;
2. Identification of the hypotheses of cause contained in the model;
3. Preliminary screening of the hypotheses of cause for validity, relevance, and credibility;
4. Evaluation of the hypotheses of cause; and
5. Development of research approaches for testing the hypotheses of cause, if necessary.

These tasks were accomplished by using a set of highly structured meetings and workshops (Table 1) attended by research scientists, managers, and administrators selected at an initial project scoping meeting (Holling 1978, Environment Canada 1982). This approach involved the development of a model of the relationships between important natural and anthropogenic stresses and forest dynamics. The modeling process forced workshop participants to think in interdisciplinary, quantitative terms about these relationships and their effects. The resulting model yielded a set of linkages describing the interrelationships between the physical, chemical, and biological processes of spruce-fir forests and the various natural and anthropogenic stresses, and could therefore be disaggregated into hypotheses of cause.

The hypotheses of cause were screened and evaluated at a second workshop with a set of structured exercises. First, the hypothesis was clarified so that a consensus was reached regarding the structure of the hypothesis and its associated linkages. Second, the evidence for and against each link or causal mechanism in the hypothesis of cause was documented. This evidence could consist of published data on the spruce-fir system, published data on other forest systems or the expertise of workshop participants. Then, based on the evidence for and against each link in the hypothesis, one of the following conclusions was reached:

1. Unlikely and not worth testing with research;
2. Already sufficiently tested;
3. Possible, but too difficult to test; or
4. Possible and worth testing with research.

The rationale for reaching the particular conclusion was documented for each hypothesis. If it was decided a hypothesis of cause should and could be tested, participants then developed appropriate research strategies.

Conceptual Model

A conceptual model (Fig. 1) was developed at the first workshop which consisted of a set of natural and anthropogenic stresses (Table 2) which influence the physiological processes and, in turn, are manifested in changes in tree growth, yield, mortality and decline symptoms. The model was further defined by specifying the valued ecosystem components which are ultimately influenced by the stresses. These consisted of (1) growth and yield variables (stem density, basal area, volume) which are appropriate for commercial stands, and (2) aesthetic attributes (leaf area index, foliage color, species composition, percent dead biomass, genetic variation) which are of more interest in the recreational, high-elevation forests.

Table 1.--Project schedule

Project Task	Date and Location	Purpose
Scoping Meeting	Sept. 30-Oct. 1, 1985 Broomall, PA	-develop preliminary model structure -choose workshop participants
First Workshop	Oct. 28-31, 1985 Downington, PA	-develop conceptual model -assign responsibilities for providing data for model relationships and parameters
Interim Report	Nov. 1-Dec. 2, 1985 AEA Inc. offices and Philadelphia, PA	-document first workshop and develop hypotheses of cause
Model Development	Nov.-Dec., 1985 AEA Inc. offices	-construct computer model and develop model communication overheads -initiate model transfer to Forest Service
Second Workshop	Jan. 6-10, 1986 Philadelphia, PA	-present prototype computer model -evaluate hypotheses of cause
Project Documentation	mid-Jan.-March 1986 AEA Inc. offices	-model description -evaluation of hypotheses and research recommendations -model transfer guide

Table 2.--List of natural and anthropogenic stresses

A. Climate
    -precipitation (drought/excess water)
    -temperature
    -winter conditions (ice)
    -length of growing season
    -wind
    -cloud water

B. Biological
    -balsam wooolly adelgid
    -spruce beetle
    -spruce budworm
    -ghost moth
    -pathogens
        -root
        -stem
        -foliage
    -internal obligates

C. Normal Stand Development
    -aging
    -site factors
        -moisture retention capacity
        -soil texture
        -soil fertility
        -soil aeration
    -fire (protection)
    -crowding
    -genetic variation
    -marine salts

D. Stand Treatment
    -cutting and harvesting

E. Chemicals/Pollutants
    -sulfur
    -nitrogen
    -ozone
    -trace metals (Pb, Cd, Zn, Mn, V, Mb, Cu, Al)
    -organics
        -synthetic
        -natural
    -hydrogen peroxide
    -acidity

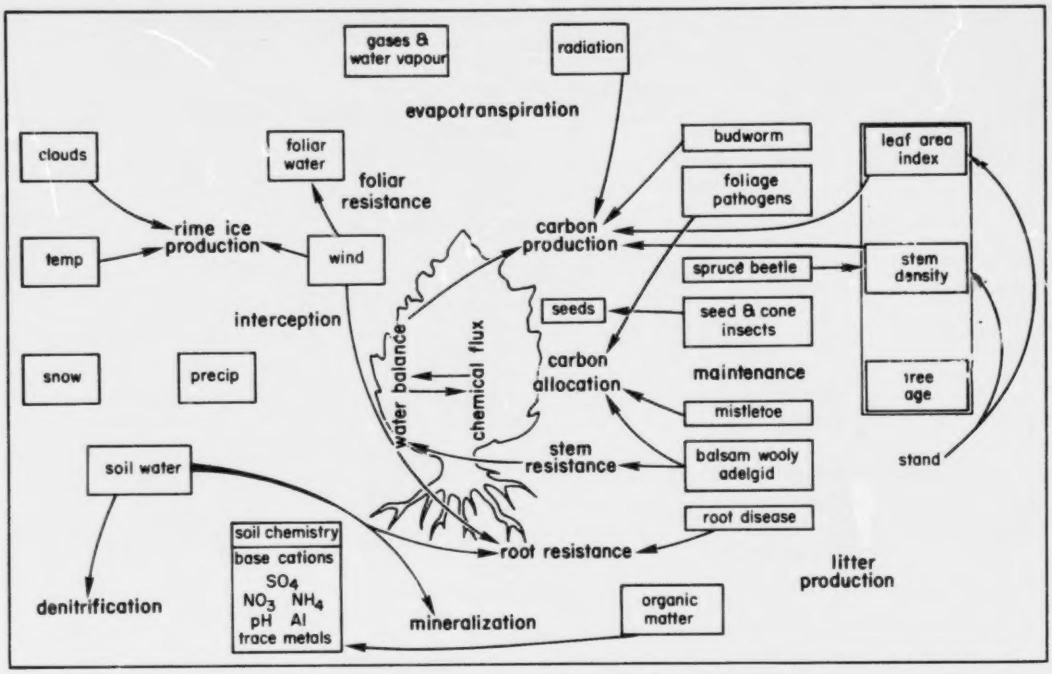

gases & water vapour
radiation
evapotranspiration
clouds
foliar water
foliar resistance
budworm
leaf area index
foliage pathogens
rime ice production
temp
wind
carbon production
spruce beetle
stem density
seeds
seed & cone insects
interception
water balance
chemical flux
carbon allocation
maintenance
snow
precip
tree age
mistletoe
soil water
stem resistance
balsam wooly adelgid
stand
root disease
soil chemistry
base cations
SO_4
NO_3 NH_4
pH Al
trace metals
root resistance
litter production
denitrification
mineralization
organic matter

Figure 1.--The conceptual model. Dark arrows are effects, shaded lines are fluxes, boldface entries are processes, and boxed entries are stresses or valued ecosystem components and indicators.

Given the list of stresses and valued ecosystem components, the model was subdivided into five components, as follows:

1. CLIMATE - responsible for considering important natural abiotic stresses on spruce-fir forests;
2. BIOLOGY - responsible for considering important natural biotic stresses on spruce-fir forests;
3. CHEMISTRY - responsible for the distribution of anthropogenic pollutants throughout the stand and for soil chemistry;
4. TREE - responsible for considering all climatic, biological and chemical effects on tree water balance, chemical flux, carbon assimilation, and carbon allocation; and
5. STAND INTERFACE - responsible for integrating tree level dynamics into stand level indicators.

The variables considered in each of these components and the information transfer required to capture the effects of stresses on the indicators are shown in Fig. 2. It is important to recognize that each piece of information listed in the matrix represents all or part of a hypothesis relating to spruce-fir dynamics. For example, the tree subgroup requested the root solution concentrations of various trace metals from the chemistry subgroup because one of the hypotheses of spruce-fir decline is that increased soil concentrations of trace metals will decrease fine root biomass which will, in turn, disrupt the tree water and nutrient balance.

The conceptual model was presented at the first workshop and used in two ways during the remainder of the project. First, it was used as the basis for the development of a computer simulation model of the spruce-fir system. Second, it was disaggregated to a set of hypotheses of cause for evaluation at the second workshop.

Simulation Model

The conceptual model developed at the first workshop was used as the framework for developing a distant-independent computer simulation model of the spruce-fir decline problem. This model will be used by the SFRC as a focus for research results and as a tool for interdisciplinary and interagency communication. It is also the first prototype of a model which will be used for predicting effects of changes in atmospheric deposition loadings on spruce-fir forests.

To From	BIOLOGY/CLIMATE	CHEMISTRY	TREE	STAND INTERFACE
BIOLOGY/ CLIMATE		- % time of cloud immersion - precipitation •total •frequency/duration - temperature - depth of snow pack - average wind speed	- foliage consumed * - % roots infested * - % bark infested * - # trees infested by adelgid * - maximum temperature decrease and duration - degree days > threshold - depth of snow pack - # of days with rime ice - solar radiation - % time of cloud immersion - water stress index	- % trees infested by spruce beetle*
CHEMISTRY	- ozone concentration (hrs > threshold) - sulfate concentration at air/foliage interface - concentrations of Cd, Cu, Zn, Hi at soil/root interface		- concentration of SO_2, NO_x, ozone at air/foliage interface and # hours > threshold - foliage solution concentration of peroxide, sulfate, nitrate, ammonium, H^+ - root solution concentrations of Ca, Mg, K, Al, Mn, Pb, P, H^+	
TREE	- foliage biomass* - length of fine roots (< 3 mm), length of dead and live woody roots, by soil horizon	- uptake and excretion of chemicals by foliage and roots		- change in basal area growth* - change in mortality* - viable seeds produced, by species - leaf area*
STAND INTERFACE	- leaf area index - % exposed edge of stand - stand composition	- height distribution of foliage - leaf area index	- # stems *	

* By species and size class

Figure 2.--Information transfers among components. Entries are information passed from the submodel listed on the left to the submodel listed on the top. Climate and biology are combined to reflect the way in which the matrix was developed at the first workshop.

Each disciplinary component is a submodel within the prototype model. Participants at the first workshop developed functional relationships for the simulation model using published and unpublished information from the spruce-fir system and other forest ecosystems, as well as professional judgement based on scientific experience with important physical, chemical, and biological processes.

Rather than develop a new stand model, participants decided to use the FIBER model developed by Solomon et al. (1986) to simulate the growth of mixed stands in the Northeastern U.S. This is an empirically based model which uses a two-stage matrix projection technique to simulate the change in stand composition by simulating growth, mortality and ingrowth. One stage of the model consists of regression equations relating transition probabilities for tree diameter growth to stand density, tree size and proportion hardwoods. In the other stage, these probabilities are used in projection matrices which predicts the stand diameter distribution over time. In addition, equations were developed to predict ingrowth into the smallest allowable diameter class (5 inches). The model was originally calibrated from three data sets which consisted of 359 permanent plots in a softwood forest (Penobscot Experimental Forest, Bradley, ME), 48 plots in an uneven-aged northern hardwood forest (Bartlett Experimental Forest, Bartlett, NH) and over 2500 plots from northern Maine, New Hampshire, northern New York and Vermont. It allows the user to simulate the effects of several management practices and silvicultural treatments over a range of stand densities and harvest intervals. Stands can be managed either by stating the stocking level (basal area, cubic volume) or by using B-level stocking charts. Thinning is achieved by thinning from above, thinning from below, thinning along a q-line, removal of trees from any diameter class, or thinning uniformally across all diameter classes. Stand composition is provided as a frequency distribution of stems for each species in one-inch diameter classes from 5 to 30 inches. Additional attributes of the stand can be estimated in relation to the diameter of the stem classes (species, size) present during a simulation. Thus a stand interface submodel had to be constructed to link the effects of the climate, biology, chemistry, and tree submodels to FIBER.

The general order of calculations for the simulation model is given in Figure 3. The model year begins on March 1. The climate submodel runs on a weekly time step and provides the chemistry and tree submodels with a weekly description of the physical environment within the stand. The biology submodel then computes the effects of pests given current measures of important stand variables. The chemistry submodel uses the weekly information provided by the climate submodel as inputs to a monthly nitrogen dynamics model. It also uses total stand biomass increment to compute relative soil nitrogen available to the trees. The tree submodel uses the weekly information provided by the climate submodel to compute important annual measures of the physical environment, the presence of extreme climatic events, along with effects of biota and relative nitrogen availability to determine realized tree growth and tree mortality. The stand interface submodel uses realized tree growth and mortality to

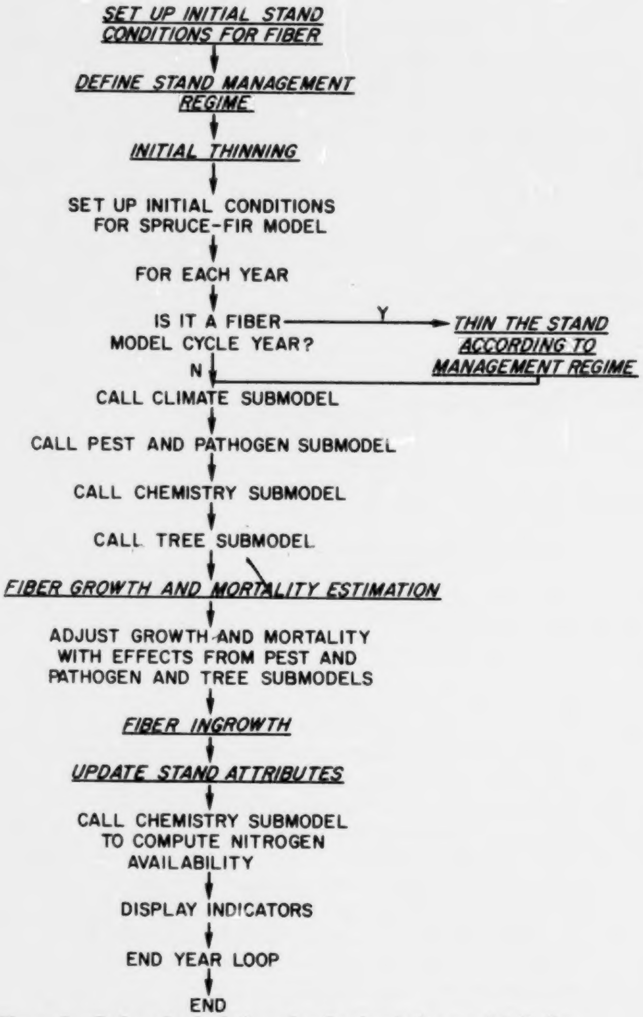

SET UP INITIAL STAND CONDITIONS FOR FIBER
DEFINE STAND MANAGEMENT REGIME
INITIAL THINNING
SET UP INITIAL CONDITIONS FOR SPRUCE-FIR MODEL
FOR EACH YEAR
IS IT A FIBER MODEL CYCLE YEAR?
Y
THIN THE STAND ACCORDING TO MANAGEMENT REGIME
N
CALL CLIMATE SUBMODEL
CALL PEST AND PATHOGEN SUBMODEL
CALL CHEMISTRY SUBMODEL
CALL TREE SUBMODEL
FIBER GROWTH AND MORTALITY ESTIMATION
ADJUST GROWTH AND MORTALITY WITH EFFECTS FROM PEST AND PATHOGEN AND TREE SUBMODELS
FIBER INGROWTH
UPDATE STAND ATTRIBUTES
CALL CHEMISTRY SUBMODEL TO COMPUTE NITROGEN AVAILABILITY
DISPLAY INDICATORS
END YEAR LOOP
END

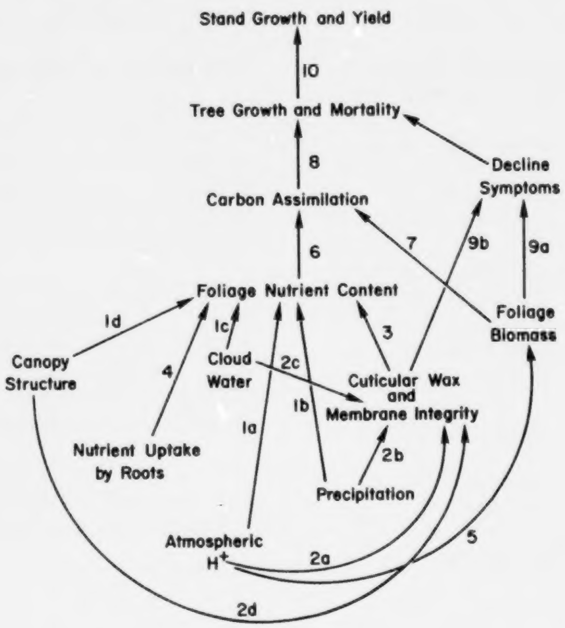
Figure 3.--Order of calculations for the simulation model. Italics are carried out within FIBER.

modify the estimates of growth and mortality provided by the FIBER model and computes various indicators of interest and information required by the other submodels the following year.

The model is currently based on too little data and too little understanding to be of any predictive use. At this point, it is more appropriate to examine qualitative model behavior in response to alternate stresses and to use the model results to suggest model refinements which could be made.

Several scenarios were simulated which have led to the following preliminary conclusions. First, although direct stress effects are manifested in the dynamics of spruce and fir, they are also manifested as indirect competitive effects on other species. Paper birch, for example, has greater basal area and tree density in those scenarios in which red spruce has lower basal area and stem density caused by stress effects. Thus, the value of simulating stress effects only on a particular set of species in a stand must be carefully examined since this approach may be valid only if other species in the stand are not influenced by these stresses. Secondly, the results show the risk in using a stand model based on statistical regressions fitted to a set of observed data. For example, the rate of change in spruce and fir basal area are the same in high elevation stands as they are in low elevation stands, which indicates that the stand model by itself does not distinguish between growth differences in low and high elevation sites. The temperature difference in the two scenarios was not enough to cause a noticeable difference in the basal area growth rate between the two stands. Conversely, the influence of wind-induced root damage is sufficiently large to cause a difference in basal area growth rate between the two stands. However, the effect of wind on stand dynamics has likely already been partly included in the regression parameters and double counting of stress effects is probably happening, which results in overestimating the effect of wind damage.

The decline of red spruce and fir is caused by leaching of nutrients from foliage and foliage injury as a result of acidic deposition.


Stand Growth and Yield
10
Tree Growth and Mortality
8
Decline Symptoms
Carbon Assimilation
6
7
9b
9a
Foliage Nutrient Content
Id
Ic
3
Foliage Biomass
Canopy Structure
4
Cloud Water
2c
Cuticular Wax and Membrane Integrity
Ib
Ia
Nutrient Uptake by Roots
2b
Precipitation
Atmospheric H^+
2a
5
2d

Linkages

1. Atmospheric deposition of H^+ onto foliage leaches nutrients from the foliage. Atmospheric deposition may be dry (Ia), in precipitation (Ib), or in cloud water (Ic). The deposition of H^+ is mediated by canopy structure (interception) (Id).
2. Atmospheric deposition of H^+ removes the cuticular wax and destroys membrane integrity of foliage. Atmospheric deposition may be dry (2a), in precipitation (2b), or in cloud water (2c). The deposition of H^+ is mediated by canopy structure (interception) (2d).
3. Removal of cuticular wax reduces foliage nutrient content by increasing leaching.
4. Increased nutrient uptake by roots will compensate for foliage nutrient losses caused by leaching.
5. Increasing deposition of atmospheric H^+ will decrease foliage biomass.
6. A decrease in foliage nutrient content will decrease carbon assimilation.
7. A decrease in foliage biomass will decrease carbon assimilation.
8. A decrease in carbon assimilation will decrease tree growth and increase tree mortality.
9. A decrease in foliage biomass (9a), a loss of cuticular wax and membrane integrity (9b), and a decrease in tree growth with increased tree mortality (9c) caused by foliar leaching creates observed decline symtoms in red spruce and fir.
10. Tree growth and mortality influences stand growth and yield.

Figure 4.--An example of a linkage diagram for a hypothesis of cause.

Table 3.--Hypotheses of cause

The decline of red spruce and fir is caused by:

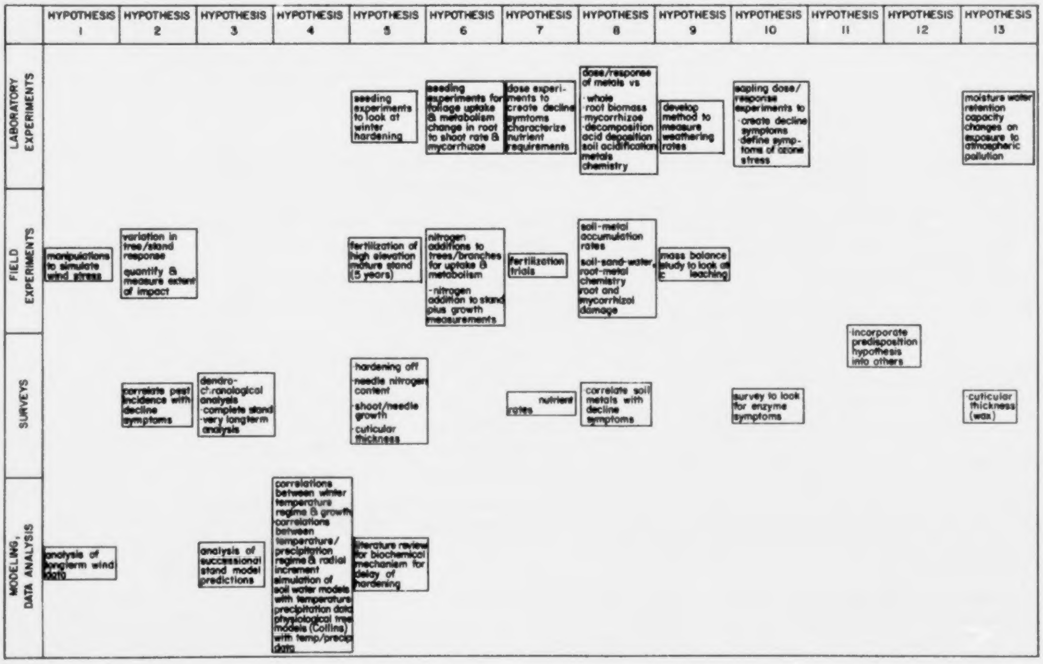
Hypothesis 1 -	wind in association with wood-decaying fungi
Hypothesis 2 -	pests and pathogens
Hypothesis 3 -	forest successional processes
Hypothesis 4 -	changes in moisture and temperature regimes
Hypothesis 5 -	nitrogen fertilization causing foliar injury
Hypothesis 6 -	nitrogen fertilization causing water and nutrient stress
Hypothesis 7 -	acidic deposition causing foliar injury
Hypothesis 8 -	acidic deposition causing increased soil acidity and soil metal concentrations
Hypothesis 9 -	acidic deposition causing reduced soil nuitrients
Hypothesis 10 -	atmospheric oxidants causing foliar injury
Hypothesis 11 -	trace metal deposition causing foliar injury
Hypothesis 12 -	interacting effects of atmospheric deposition and drought which predispose the forests to attack by pests and pathogens
Hypothesis 13 -	acidic deposition causing water stress

Finally, the results of the model scenarios suggest that it may be very difficult to detect the effect of a stress in the spruce-fir ecosystem. The effects of a decrease in the temperature regime and a five-year drought are very slight if species basal area and tree density are taken to be the measurement indicators. However, other indicators in the model appear to be more sensitive measures of the effects of stresses. For example, spruce foliage biomass per tree and tree density in the mature age classes show greater response to stresses than either species basal area or tree density.

Evaluation of Hypotheses of Cause

The conceptual model was disaggregated into thirteen hypotheses of cause which were reviewed and refined at a one-day technical meeting with a number of project participants (Table 3). The hypotheses of cause were then evaluated at the second workshop for their validity and testability. The results of this evaluation form the rationale and basis for the research recommendations.

For each hypothesis, a linkage diagram and a description of the important physical, chemical, and biological processes operating at each linkage were provided. Figure 4 illustrates this for a typical hypothesis. The evidence for and against each hypothesis was then provided by the participants for each linkage in the hypothesis, for each causal mechanism contained in the hypothesis, or for the hypothesis as a whole, depending on the nature of the subgroup discussions at the second workshop. The conclusion as to validity and testability for the hypothesis was given, and recommendations for research, if any, were presented.



	HYPOTHESIS 1	HYPOTHESIS 2	HYPOTHESIS 3	HYPOTHESIS 4	HYPOTHESIS 5	HYPOTHESIS 6	HYPOTHESIS 7	HYPOTHESIS 8	HYPOTHESIS 9	HYPOTHESIS 10	HYPOTHESIS 11	HYPOTHESIS 12	HYPOTHESIS 13
LABORATORY EXPERIMENTS					seeding experiments to look at winter hardening	seeding experiments for foliage uptake & metabolism change in root to shoot rate & mycorrhizae	dose experiments to create decline symtoms characterize nutrient requirements	dose/response of metals vs · whole · root biomass · mycorrhizae · decomposition acid deposition soil acidification metals chemistry	develop method to measure weathering rates	sapling dose/response experiments to · create decline symptoms · define symptoms of ozone stress			moisture water retention capacity changes on exposure to atmospheric pollution
FIELD EXPERIMENTS	manipulations to simulate wind stress	variation in tree/stand response quantify & measure extent of impact			fertilization of high elevation mature stand (5 years)	nitrogen additions to trees/branches for uptake & metabolism - nitrogen addition to stand plus growth measurements	fertilization trials	soil-metal accumulation rates soil-sand-water, root-metal chemistry root and mycorrhizal damage	mass balance study to look at C leaching				
SURVEYS		correlate pest incidence with decline symptoms	dendro-chronological analysis · complete stand · very longterm analysis		· hardening off · needle nitrogen content · shoot/needle growth · cuticular thickness		nutrient rates	· correlate soil metals with decline symptoms		survey to look for enzyme symptoms		· incorporate predisposition hypothesis into others	· cuticular thickness (wax)
MODELING, DATA ANALYSIS	analysis of longterm wind data		analysis of successional stand model predictions	correlations between winter temperature regime & growth correlations between temperature/precipitation regime & radial increment simulation of soil water models with temperature precipitation data physiological tree models (Collins) with temp/precip data	literature review for biochemical mechanism for delay of hardening								

Figure 5.--Synthesis of research recommendation.

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The research recommendations from the evaluation of the hypotheses of cause are summarized in Figure 5 which organizes the research recommendations by hypothesis (columns) and according to the general type of research recommended (rows). It should be noted that there are a number of common areas where research coordination and cooperation may and probably should occur. For example, similar dose response experiments were suggested as research for Hypotheses 5, 6, 7, 8 and 10. For Hypotheses 5, 6, and 7, research recommendations involve similar field manipulations of entire stands with chemical inputs. To minimize logistic costs, the surveys suggested could be performed together as part of a single effort. Also, the predisposition hypothesis (Hypothesis 12) should be a part of all research efforts, where possible.

The set of research recommendations contain both intensive research (laboratory and field experimentation) and extensive research (broad surveys, modeling and data analysis). The participants recognize that each hypothesis will probably have to be tested at both the intensive and extensive level. The challenge has been to develop an overall research strategy which can test the hypotheses at both of these levels. The general research strategy visualized by workshop participants (Figure 6) was found to contain several important components. The first component develops the understanding of whether suspected abiotic, biotic, and anthropogenic sources of stress described in Table 2 influence the growth and mortality of spruce and fir trees and, if they do, how the severity of the growth and mortality effects vary with different levels and patterns of the stresses (Elements A and B of Figure 6). The laboratory and field experiments suggested in Figure 5 comprise this first component of the research strategy. The second component develops the understanding of whether suspected abiotic, biotic, and anthropogenic sources of stress produce symptoms and, if they do, how the severity of the symptoms expressed varies with different levels and patterns of the stresses (Elements A and C of Figure 6). The laboratory and field experiments of Figure 5 also comprise this second component of the research strategy. The third component of the research strategy, derived from the first two, develops the understanding of what different types and severities of symptoms mean in terms of expressed tree and stand damage (Element D of Figure 6). This will be of critical importance in the testing of the hypotheses, particularly at extensive scales, because symptoms of effect are usually easier to document and quantify than actual tree and stand damage on an extensive basis. The fourth component is a regional survey of levels and patterns of stress and the symptoms (Element E of Figure 6). This regional survey should be able to show which hypotheses of cause cannot be valid on an extensive basis (from the results of the second component). It should also be able to quantitatively describe the magnitude of forest damage resulting from those causal mechanisms which are valid on an extensive basis (from the first and third components).

Research conducted in the SFRC will be affected by a number of uncertainties, and it is important to keep these uncertainties in mind when designing and conducting the research. First, not all the symptoms of effect for each causal mechanism reviewed in the project are known. Therefore, it is impossible to know what to look for in testing some of the hypotheses. Obviously, productivity decline is a necessary symptom for all hypotheses. The necessary symptoms for some causal mechanisms, such as wind damage, are well known but those for others, such as metal influences on decomposition rates, are poorly understood. The symptomotology of each causal mechanism must be worked out. Second, the current regional characterization of the decline is inadequate. Project participants with different experiences in high elevation spruce-fir forests have different descriptions of what

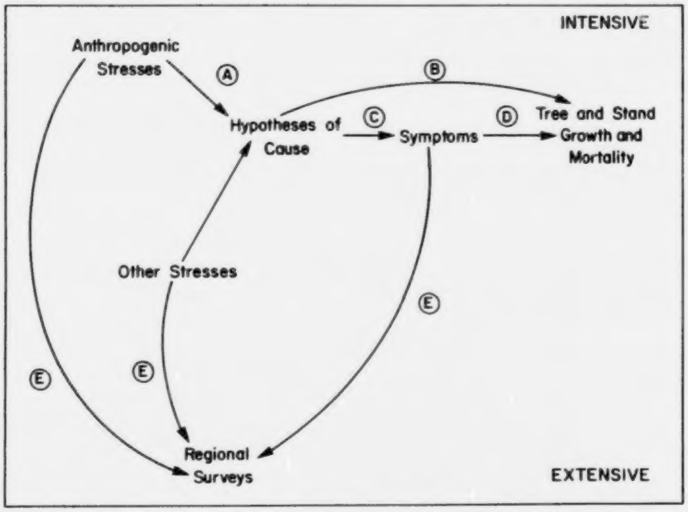

Figure 6.--A general research strategy.

the specific crown symptoms are, the tree age classes affected, and so on. Regional characterization should agree with the symptoms of effect for the causal mechanisms in the model. The survey of Weiss et al. (1985) is a good first step. However, to be complete, it must be linked with a survey emphasizing stresses, and expanded to cover a broader spatial area, the range of stand and site types likely to be encountered.

Finally, the SFRC will probably be hindered by a relatively poor understanding of the natural and historical dynamics of spruce-fir systems, a general lack of specific knowledge on the historical dynamics of these forests and, for the most part, an absence of notable symptoms of forest decline to provide the dependent variable for the research. As such, it may be difficult to describe and quantify past and present magnitudes of natural variation in spruce-fir growth and mortality, or to assess the effects of any anthropogenic influences.

Models can be used a number of ways. Detailed mechanistic models of single stands, similar to acidification models of watersheds such as ILWAS (Chen et al. 1982), could be developed. These would represent a summary of all understanding gained in particular areas, say, for the intensive research plots, but would be difficult to parameterize for other sites, largely because of their large data requirements.

Simple statistical models, correlating stresses with decline symptoms, would be another type of useful model. Such a model could provide clues and circumstantial evidence as to what the likely causes of decline might be. The predicative capabilities of this type of model are restricted, however, since statistical model parameters are derived from a set of observations and the predictive reliability beyond the boundaries of the observation set is uncertain.

The consequences of emissions reductions on spruce-fir forest growth is an extremely important policy question and one that can likely only be answered adequately with a regional model. If attempted, such a model should be mechanistically based, but simple enough in structure that it can be easily parameterized for most stands. In addition, the model should be responsive to emissions or alternate levels of pollutant deposition. It may not be possible, presently, or ever, to develop such a model. Given the potention benefits of such a model, however, it is recommended that priority should be given to assessing whether or not such a model could be constructed. This assessment would be immensely valuable in deciding what would be needed in developing such a model and the magnitude of the uncertainties involved in the predictions.

The current simulation model has the potential to evolve into part of the regional model described above. It is simple in structure and already contains many of the stress effects of interest. Perhaps the most important immediate use of this model is as a focus for communication among the research scientists, research managers and decision makers in the various constituencies with interest in the spruce-fir decline problem, or as a means of evaluating research results. Major improvements to the model may be possible in the immediate future by allowing project participants the opportunity to make refinements and by exposing it to a broader group of participants.

The Research Plan

The knowledge and insight gained from the research planning exercise was extremely valuable when the SFRC began developing a research plan for USDA Forest Service/EPA approval. After several revisions and peer review, a plan was approved in April 1986. Eight scientific questions have been identified (Table 4). The first two deal with policy question 1 and Six with policy question 2. The various types of suggested experiments for those questions consist of controlled laboratory, controlled field and uncontrolled field studies. As of October 1986, 32 projects are funded (Table 5).

Table 4.--Scientific questions addressed by the Spruce-fir Research Cooperative

Policy Question No. 1 Is there a significant problem of forest damage in North America which might be caused by acid rain, its precursors, and associated pollutants (e.g., SO_x, NO_x, H^+ O_3, H_2O_2, or hydrocarbons)?

Scientific Questions:

1.1 Are changes in growth and mortality and the presence of unusual foliar symptomology in red spruce-fir forests greater than can be attributed to typical trends and levels of natural variability? (3,5,8,10,13,16,21,23,25,27,28,29,32)

1.2 What spatial patterns, if any, exist in growth and mortality and in the presence of unusual symptomology in red spruce-fir forests and how do these patterns relate to spatial patterns of pollutant exposure? (1,3,4,5,6,7,8,9,10,13,16,18,21,23,25,27,28,29,32)

Policy Question No. 2 If so, what is the causal relationship between acid rain, its precursors, and associated pollutants and forest damage in North America?

Scientific Questions:

2.1 What is the effect of sulfur and/or nitrogen derived pollutants on red spruce and fir through (1) the mechanism of direct toxicity to roots, mycorrhizae or soil microbial populations by the mobilization of metals and (2) the mechanism of leaching of nutrients from the rooting zone by acid deposition resulting in altered tree water and nutrient balances? (8,14)

2.2 What is the effect of sulphur and/or nitrogen derived pollutants alone or in combination with oxidants on red spruce and fir through the mechanism of increased leaching of foliar nutrients? (8,11,12,26)

2.3 What is the effect of sulfur and/or nitrogen derived pollutants alone or in combination with oxidants on red spruce and fir morphology by the mechanism of carbon allocation and physiological processes? (2,11,12,17,20,22,24,26)

2.4 What is the effect of nitrogen compounds alone or in combination with oxidants on red spruce and fir through the mechanism of increased winter damage due to altered physiology? (11,17,24,26,30,31)

2.5 What is the effect of sulfur and/or nitrogen derived pollutants alone or in combination with oxidants on red spruce and fir through the mechanism of disrupting reproduction or regeneration? (Not being considered by The Spruce-fir Research Cooperative)

2.6 What is the effect of sulfur and/or nitrogen derived pollutants alone or in combination with oxidants on red spruce and fir through the mechanism of altered susceptibility to insects and pathogens? (3,12,25)

The numbers in parentheses following each question refer to the projects listed in Table 5.

Table 5.--Funded Projects

1. Franklin T. Bonner (USDA Forest Service, SOFES). Quality of seed produced in declining Spruce-fir forests of the eastern United States.

2. Frank Thornton (Tennessee Valley Authority). A field chamber study of the response of red spruce to cloud interception and/or ozone.

3. Robert I. Bruck (North Carolina State University). Interactions of spruce-fir pathogens, insects and ectomycorrhizae on the etiology and epidemiology of boreal montane decline in the southern Appalachian Mountains.

4. Donald H. DeHayes (The University of Vermont). Genetic Uniformity: A fundamental mechanism for red spruce decline.

5. Charles W. Dull (USDA Forest Service, FPM). Detection and evaluation of spruce-fir decline in the southern Appalachian using remote sensing. (completed).

6. Robert T. Eckert (University of New Hampshire). Genetic variation in red spruce pollution response.

7. Peter P. Feret (Virginia Polytechnic Institute and State University). The impact of environment and genotype on the reproductive fitness of Fraser fir from Mt. Rogers and Mt. Mitchell.

8. Ivan J. Fernandez (University of Maine). An integrated study of atmospheric deposition and nutrient cycling in commercial spruce-fir ecosystems.

9. Stewart M. Goltz (The University of Maine). Management and environmental monitoring at Howland Maine.

10. James F. Hornig (Dartmouth College). Studies of a spruce-fir forest at the Dartmouth-Mt. Moosilauke Research Forest.

11. Jay S. Jacobson (Boyce Thompson Institute). Test of the nitrogen fertilization hypothesis of red spruce decline.

12. Keith Jensen (USDA Forest Service, NEFES). Impact of ozone and acid deposition on foliar leaching and growth of red spruce seedlings

13. Arthur Johnson (University of Pennsylvania). Quantifying spruce decline and associated forest characteristics at Whiteface Mountain, New York.

14. Arthur Johnson (University of Pennsylvania). The effects of acid precipitation on nutrient leaching, and metal mobilization on Whiteface Mountain, New York.

15. Siamak Khorram (North Carolina State University). Design and development of a base entry and management system for the Spruce-fir Research Cooperative.

16. Lynn A. Maguire (Duke University). Experimental design and forest modeling for spruce-fir decline in the southern Appalachians.

17. Sandy McLaughlin (Oak Ridge National Laboratory). Interactive effects of natural and anthropogenic factors on growth and physiology of red spruce.

18. Stephen Mueller (Tennessee Valley Authority). Acid inputs to high elevation forest in the southeastern United States -- cloud contact, wet and dry deposition.

19. Harvey L. Ragsdale (Emory University). Temporal patterns of tree diameter growth in southeastern high elevation Spruce-fir ecosystems (Completed).

20. Curtis Richardson (Duke University). Effects of atmospheric deposition on red spruce: A free radical-based approach.

21. Wayne P. Robarge (North Carolina State University). Quality assurance/quality control program for analysis of water, soil and plant samples.

22. John Seiler (Virginia Polytechnic Institute and State University). Impact of ozone and simulated acid rain on the growth, physiology and water relations of Fraser fir.

23. Dale Solomon (USDA Forest Service, NEFES). Modeling stand dynamics of spruce-fir forest in the northeast.

24. Michael H. Unsworth (Institute of Terrestrial Ecology, Scotland). Frost hardiness of red spruce in relation to forest decline and effects on red spruce of winter exposure to SO_2 and NO_2.

25. Philip M. Wargo (USDA Forest Service, NEFES). Relationship of root vitality to decline in spruce-fir forests in the northeastern United States.

26. Leonard Weinstein (Boyce Thompson Institute). Effect of ozone and soil nutrient status on the physiology of photosynthesis, carbohydrate allocation, nutrition, and winter hardiness in red spruce seedlings.

27. Carol G. Wells (USDA Forest Service, SEFES). Soil and plant tissue chemical properties associated with stand characteristics of spruce-fir in the southern Appalachians.

28. Carol G. Wells (USDA Forest Service, SEFES). Nitrogen transformation in soils of the spruce-fir ecosystems.

29. Thomas R. Wentworth (North Carolina State University). Compilation and interpretation of the vegetation data base and disturbance history of southern Appalachian spruce-fir.

30. Donald H. DeHayes (USDA Forest Service, NEFES). Mechanism of winter injury to red spruce foliage and possible complications resulting from supplemental inputs of nitrogen.

31. Ronald C. Wilkinson (USDA Forest Service, NEFES). Geographic and genetic variation in foliar cuticle development and biochemistry of epicuticular waxes of red spruce *(Picea rubens* Sarg.) in relation to winter damage and decline.

32. Shepard M. Zedaker (Virginia Polytechnic Institute and State University). Site and stand characteristics associated with potential decline and regeneration success of spruce-fir stands in the southern Appalachians.

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Appendix I.--Project Participants

SPRUCE-FIR RESEARCH PLANNING

Workshop I	Workshop II
Downingtown PA	Philadelphia, PA
October 28-31, 1985	January 6-10, 1986

Participants	Institution	Location
Ms. Mollie H. Beattie	Agency of Environmental Conservation	VT
*Dr. Franklin T. Bonner	USDA Forest Service	MS
Ms. Ann Carey	USDA Forest Service	DC
*Dr. C. Anthony Federer	USDA Forest Service	NH
Dr. Ann Fege	USDA Forest Service	PA
*Dr. Ivan J. Fernandez	University of Maine	ME
*Ms. Mary Foley	USDI, Park Service	MA
Dr. Andy Friedland	University of Pennsylvania	PA
*Mr. Lorne Greig	AEA Inc.	Ontario
*Dr. Fred Hain	NC State University	NC
*Dr. Gerard D. Hertel	USDA Forest Service	PA
Mr. Urs Hintermann	AEA Inc.	WV
Dr. Anthony Janetos	Environmental Protection Agency	DC
*Mr. Mike Jones	AEA Inc.	Ontario
*Dr. John Kadlecek	SUNY - Atmospheric Sciences Research Center	NY
*Dr. Daniel Kucera	USDA Forest Service	PA
*Dr. Alan Lucier	Nat'l Council of the Paper Industry for Air & Stream Improvement, Inc.	NY
*Dr. David MacLean	Canadian Forestry Service	NB
*Dr. Paul Manion	SUNY	NY
*Dr. Peter McNamee	AEA Inc.	Ontario
*Ms. Carolyn McQuattie	USDA Forest Service	OH
Ms. Susan Medlarz	NC State University	NC
Dr. Rich Norby	Oak Ridge National Laboratory	TN
Dr. Basil Pinker	Alabama A&M	AL
Dr. Eric Preston	Environmental Protection Agency	OR
*Dr. Kurt Riitters	Northrop Services, Inc.	OR
Dr. Douglas Ryan	Dartmouth	NH
*Dr. Don Seegrist	USDA Forest Service	PA
Dr. Katharine Sheehan	USDA Forest Service	WV
Dr. Thomas Siccama	Yale	CT
Dr. William H. Smith	Yale	CT
*Dr. Dale S. Solomon	USDA Forest Service	ME
Dr. George Taylor	Oak Ridge National Laboratory	TN
Dr. Robert Taylor	Alabama A&M	AL
*Dr. Philip M. Wargo	USDA Forest Service	CT
Mr. Tim Webb	AEA Inc.	Ontario
*Dr. David Weinstein	Cornell	NY
*Mr. Melvyn Weiss	USDA Forest Service	NH
Dr. Craig Weidensaul	Ohio State University	OH
*Ms. Betty L. Wong	USDA Forest Service	VT
*Dr. Stanley J. Zarnoch	USDA Forest Service	PA

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*Attended both workshops

Status of the Spruce-Fir Research Cooperative Program

Gerard D. Hertel, Stanley J. Zarnoch, and Theresa Arre, USDA Forest Service, Northeastern Forest Experiment Station, Broomall, PA 19008; Christopher Eagar, Great Smoky Mountains National Park, Gatlinburg, TN 37738; Volker Mohnen, State University of New York, Albany, NY 12205; Susan Medlarz, Northrop Services, Inc., Corvallis, OR 97333; located at USDA Forest Service, Northestern Forest Experiment Station, 370 Reed Road, Broomall, PA 19008.

Abstract

The Spruce-Fir Research Cooperative was formed in 1985 as part of the joint USDA Forest Service and U.S. Environmental Protection Agency (EPA) Forest Response Program (FRP). This paper describes the current condition of the spruce-fir forests in eastern North America, the support groups needed to conduct the necessary research, and a summary of the projects being funded to answer the policy and scientific questions being addressed by the Spruce-Fir Research Cooperative.

Condition of Spruce-Fir Forest

Aside from the mixed conifer forest in the San Bernadino National Forest near the Los Angeles Basin, the only significant visible decline and mortality of a U.S.'s forest possibly caused by regional air pollution is found in the high elevation spruce-fir forests of the Appalachians (VA, NC, TN, WV), Adirondacks (NY), Green Mountains (VT), and the White Mountains (NH). In January 1987, most of the scientists that have studied or are currently studying Spruce-Fir conditions met in Philadelphia, Pennsylvania. They came to a consensus on the regional condition of the spruce-fir forests. The results of that meeting follow.

Northern High-Elevation Forests

Mortality/Standing Dead

Red spruce have died (50 percent or greater reduction in number of trees) over the past 25 years at elevations about 2,900 feet in the Adirondacks, Green Mountains, and White Mountains. Mortality has not been uniformly severe at high elevations, however, reductions in live basal area (BA) of up to 60 to 70 percent between 1964 and 1986 occurred at Camels Hump, Vermont; Jay Peak, Vermont; Bolton Mt., New York; Mt. Abraham, New York; and Whiteface Mt., New York.

Above 3,300 feet, 50 percent of the red spruce are dead in stands of widely different disturbance histories and red spruce age structure. Natural disturbance of fir populations by fir waves does not fully account for spruce mortality at higher elevations.

No clear directional change in balsam fir populations has been detected. There is no regional decline of white birch.

Growth

Red spruce stem analysis and tree rings from high elevation (> 2,900 feet) stands show a regionwide abrupt, unreversed (as of 1986) reduction in growth beginning in the early 1960's. This growth decrease occurs in stands with different age structure and disturbance history, and is not explained by existing concepts of growth behavior in red spruce. Accompanying the decrease in ring width is a change in the relationship between tree-ring width and climate, which persisted for the previous 110 years, indicating a change in the response of spruce to its environment.

Growth of fir in the Adirondacks, Green Mountains, and at the Hubbard Brook does not show abrupt growth decreases as found in spruce.

Symptoms

Many crown symptoms are associated with insect, disease, and weather.

A major symptom associated with red spruce decline is dieback of terminal and lateral apices--down from the top and inward from the terminal shoots.

Reproduction and Regeneration

No statement made

Southern High Elevation Forests

Standing Dead

Of the 65,672 acres of spruce-fir type in North Carolina, Tennessee, and Virginia, 70 percent (45,711 acres) has less than 30 percent standing dead timber, 6 percent (4,425 acres) has 30 to 70 percent standing dead timber, and 24 percent (15,696 acres) has greater than 70 percent standing dead timber.

Of the 110,685 acres of spruce (no associated fir), in West Virginia, 95,578 acres had less than 10 percent standing dead spruce, 6,333 acres had between 10 to 30 percent standing dead spruce, and 1,603 acres had greater than 30 percent standing dead spruce.

Growth

At high elevations (>6,000 feet) there is unusual reduction in radial increments. This is associated with a breakdown of climate/growth relationships.

Symptoms

Crown decline classes were generally one (0 to 10 percent needle loss) and two (11 to 50 percent needle loss).

Red spruce crown condition is decreasing (more pronounced at lower elevations) in the Black Mountains, North Carolina; and Great Smoky Mountains National Park (GSMNP) but not at Mt. Rogers, Virginia.

Reproduction and Regeneration

Regeneration was found at all elevations, and abundance was proportional to overstory species composition. However, more detailed analyses are needed to understand the influence of land use and disturbance history.

Northern Low-Elevation Forests

Mortality

Mortality has been greater for spruce and balsam fir (1.3 percent per year) than for other associated species, and in the recent past, mortality of fir (2.3 percent) has exceeded that of spruce (0.5 percent).

Growth

The reduction in radial growth in low-elevation, dominant and codominant red spruce appears to be an expected, second-growth phenomenon. A recent analysis indicates that the same reduction is not consistently present in old-growth stands.

Symptoms

Only unusual symptoms on red spruce were observed on coast of Maine.

Reproduction and Regeneration

As expected, regeneration of red spruce and fir increases with increased overstory mortality.

Research Needed

It is clear from the regional summaries that something is occurring in the high-elevation forests that we cannot understand based on our current knowledge of forest and ecosystem processes. The concern over the effects of air pollutants on our forests has led to a research effort to assess air-quality impacts. The following types of research would be necessary to determine a cause and effect relationship.

1. Monitoring of gas and particulate, wet and dry pollutant deposition.
2. Systematic monitoring of forest growth and health parameters on permanent plots over extended time.
3. Coordinated field, controlled environment, and laboratory studies directed toward tree and ecosystem processes identified at risk using single pollutant and pollutant mixtures in realistic dose patterns.
4. Modeling and systems analysis to extend experimental conclusions to larger forest areas.

Spruce-Fir Research Support Groups

To solve this complex research question, the Spruce-Fir Research Cooperative (SFRC) was formed in March of 1985 as part of the Forest Response Program (FRP). The mission of the SFRC is to explain possible air pollution-related changes in the structure, function, and composition of the forest ecosystem. The cooperative addresses two questions: (1) What are the effects of air pollutants and acid deposition, if any, on eastern spruce-fir forests? and (2) Why are spruce declining at high elevations?

To accomplish its missions the SFRC depends on support from the following groups.

National Vegetation Survey (NVS)

The FRP must evaluate the current forest condition and investigate, with adequate statistical consideration, regional air pollution-related damage or death to forest trees or stands. This information is important and at the same time is a major technical issue since specific, identifiable symptoms of damage from regional levels of air pollutants are not documented. Thus, inventory and analysis research begins with the need for data, or measurement techniques to obtain data, on forest condition.

The tasks involved are top-priority work in the search for forest response information that may statistically corroborate the existence of pollution-induced damage in the field. The diversity of the eastern forests and results of earlier research make it abundantly clear that early analytical activity must be directed to specific species or other forest stand attributes. Recently published research results for the Eastern United States and Europe identify conifers in general and red spruce, balsam fir, Fraser fir, loblolly pine, and white pine specifically as the most appropriate for investigation. The NVS is currently funding 11 projects that deal with eastern spruce-fir.

Mountain Cloud Chemistry Program (MCCP)

The MCCP, an extension of the Atmospheric Exposure Cooperative, characterizes the exposure of montane forested ecosystems to atmospheric inputs (chemical, physical, and climatic). the objectives of this program are to:

1. Determine the elevational gradients in wet and dry deposition.
2. Determine the relative significance of various deposition mechanisms to the fluxes of chemical materials into and through forest canopies.
3. Determine the frequency distributions of chemical, physical, and climatic exposure.

Quality Assurance (QA) Project

The QA project assures that data collected within the SFRC are of known and sufficient quality to meet their intended use, which is the assessment of the effects of atmospheric deposition on forest ecosystems. Because of the complexity of biological research and the number of scientists involved, there is a need to monitor and control data quality and to standardize procedures where appropriate. This need is reinforced by both the long-term nature of some FRP research and the possible use of FRP results in formulating regulatory decisions. The results, therefore, may face challenges by both the scientific and legal communites.

Full documentation of procedures and results (with accompanying data quality information) will provide a scientifically and legally defensible position during controversy. For this reason, the FRP is committed to sound QA practices, which include providing QA guidelines that assure comparability of data among projects, thorough documentation of research procedures, and qualitative and quantitative evidence of data quality.

Synthesis and Integration (S&I) Project

The S&I project provides the technical focus for the FRP and develops the program's major products and outputs. Integration is achieved through a tracking system that follows the progress of each of the many individual research projects within the Research Cooperatives. Proposals are evaluated for relevance to programwide outputs and for their role in supporting or rejecting hypothesized mechanisms of air-pollution effects on trees and forests.

Synthesis is achieved through quantitative analyses and modeling of the many different kinds of data produced throughout the FRP. An approach based on biological levels of organization distinguishes seedlings, whole mature trees, stands, and regions and provides for the simultaneous analysis of data at each level while attempting to understand the connections between levels.

Extrapolation from the response to pollution of seedlings to that of mature trees, from mature trees to stands, and from stands to regions is a major task of synthesis. The ability to project the response to alternative deposition scenarios follows from an understanding of the dynamics of trees and forests affected by pollution.

Spruce-Fir Research Cooperative Projects and Outputs

Since its start-up in March of 1985 the SFRC has established six intensive research sites (Fig. 1) in cooperation with the Mountain Cloud Chemistry Program. Thirty-one projects have been funded. The SFRC deals primarily with two policy questions (Appendix) and eight scientific questions. Policy Question 1 and 2 list the scientific questions followed by the projects that have been funded to answer those questions.

Future Plans

A major review of current research was made at the Burlington, Vermont, meeting (the scientific papers in this proceedings were prepared for that meeting) to decide on future direction. All funded investigators and a small group (14) of German scientists participated in that activity. Any new major research activities must begin in the 1988 growing season if we hope to have any significant findings by the fall of 1989.

Appendix

Policy Question 1. *Is there a significant problem of forest damage in North America which might be caused by acidic deposition, alone or in combination with other pollutants?*

Scientific Questions

1.1 Are changes in growth and mortality and the presence of unusual foliar symptomatology in red spruce-fir forests greater than can be attributed to typical trends and levels of natural variability?

1.2 What spatial patterns, if any, exist in growth and mortality and in the presence of unusual symptomatology in red spruce-fir forests and how do these patterns relate to spatial patterns of pollutant exposure?

Principal Investigator/Project	*Outputs*
Characterization of Vegetation, Soils, Insects and Pathogens	
1. Arthur Johnson (University of Pennsylvania). Quantifying spruce decline and associated forest characteristics at Whiteface Mountain, New York.	Determination of extent of dieback and decline. Evaluation of effects of soil and foliar chemistry and pathogens on spruce decline.
2. James F. Hornig (Dartmouth College). Studies of a spruce-fir forest at the Dartmouth-Mt. Moosilauke Research Forest.	Evaluation of relationship of spruce-fir growth and vigor to climate, pest/pathogen occurrence, natural cycles of disturbance, and site specific forest stand dynamics.
3. Shepard M. Zedaker (Virginia Polytechnic Institute and State University). Site and stand characteristics associated with potential decline and regeneration success of spruce-fir stands in the southern Appalachians.	Description of current stand conditions and relationship to site characteristics. Evaluation of regen. success, biomass relationships, and long-term changes in composition and growth of southern spruce-fir stands.

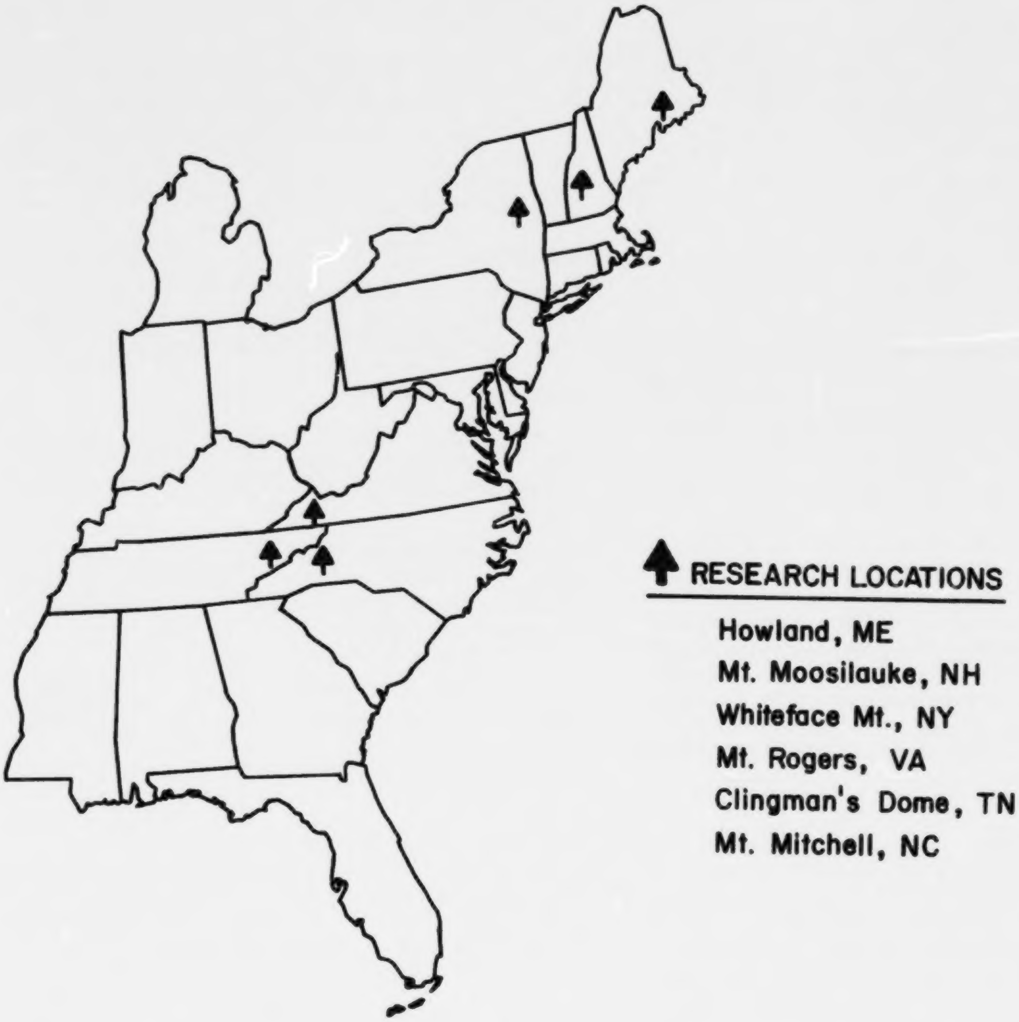
RESEARCH LOCATIONS
Howland, ME
Mt. Moosilauke, NH
Whiteface Mt., NY
Mt. Rogers, VA
Clingman's Dome, TN
Mt. Mitchell, NC

Figure 1.--Six intensive research sites.

4. Carol G. Wells (USDA Forest Service). Soil and plant tissue chemical properties associated with stand characteristics of spruce-fir in the southern Appalachians.	Evaluation of the relationship between soil, root, and foliage characteristics and symptoms, location, elevation, slope position, and exposure.
5. Carol G. Wells (USDA Forest Service). Nitrogen transformation in soils of the spruce-fir ecosystem.	Seasonal characterization of N cycle in relation to elevation, exposure, and stand characteristics. Evaluation of potential for soil N to affect tree nutrition, seasonal N availability extremes, cold hardening, excess N leaching losses.
6. Robert I. Bruck (North Carolina State University). Interactions of spruce-fir pathogens, insects, and ectomycorrhizae on the etiology and epidemiology of boreal and montane decline in the southern Appalachian Mountains.	Visual key of insect, pathogens, ectomycorrhizae for Appalachians. Assessment of pest/pathogen damage to spruce-fir. Sampling technique for ectomycorrhizae.
7. Charles W. Dull (USDA Forest Service, Southern Region). Detection and evaluation of spruce-fir decline in the southern Appalachians using remote sensing.	Aerial photography of 20 research plots. Delineation of boundaries of spruce-fir and associated standing dead.
8. Thomas R. Wentworth (North Carolina State University). Compilation and interpretation of the vegetation data base and disturbance history of southern Appalachian spruce-fir.	Bibliography of research on spruce-fir. Historical data base. Photo-monitoring network to document future changes.
9. Bruce L. Parker (University of Vermont). The ghost moth, *Hepialus gracilis*, and red spruce decline.	Incidence and impact of ghost moth in NH, VT, and NY.
10. Philip M. Wargo (USDA Forest Service). Relationship of root vitality to decline in spruce-fir forests in the northeastern United States.	Evaluation between crown condition and root condition, carbohydrate reserves, mycorrhizal infection and elevation.

Modeling

11. Lynn Maguire (Duke University) Experimental design and forest modeling for spruce-fir decline in the southern Appalachians.	Document analyzed version of FORET to represent effects of air pollution in spruce-fir forests.
12. Dale Solomon (USDA Forest Service). Modeling stand dynamics of spruce-fir forests in the Northeast.	A two stage matrix model of spruce-fir forests under ambient environmental conditions. Modifications due to elevation and pollution.

Genetics

13. Franklin T. Bonner (USDA Forest Service). Quality of seed produced in declining spruce-fir forests of the Eastern United States.	Comparison of seed quality in declining and healthy forests.
14. Donald H. DeHayes (University of Vermont). Genetic uniformity: a fundamental mechanism for red spruce decline.	Assessment/comparison of spruce-fir vigor throughout the NE. Evaluation of relationship of vigor to genetic diversity, environmental characteristics, and pollution.
15. Robert T. Eckert (University of New Hampshire). Genetic variation in red spruce pollution response.	Evaluation of relationships between 1) genotype and C allocation under O_3 pollution and 2) decline symptomatology and hybridization.
16. Peter P. Feret (Virginia Polytechnic Institute and State University). The impact of environment and genotype on the reproductive fitness of Fraser fir from Mt. Rogers and Mt. Mitchell.	Quantification of environmental and genetic sources of variation, and the effect of ozone on the reproductive fitness of Fraser fir.

Policy Question 2. *What is the causal relationship between acidic deposition, alone, or in combination with other pollutants; and forest damage in North America?*

Scientific Question

2.1 What is the effect of sulfur and/or nitrogen derived pollutants on red spruce and fir through (1) the mechanism of direct toxicity to roots, mycorrhizae or soil microbial populations by the mobilization of metals and (2) the mechanism of leaching of nutrients from the rooting zone by acid deposition resulting in altered tree water and nutrient balances?

Principal Investigator/Project	Outputs
17. Ivan J. Fernandez (University of Maine). An integrated study of atmospheric deposition and nutrient cycling in a commercial Northeast spruce-fir ecosystem.	Evaluation of effect of atmospheric deposition on nutrient cycling in commercial spruce-fir forests.
18. Arthur Johnson (University of Pennsylvania). The effects of acid precipitation on nutrient leaching, and metal mobilization on Whiteface Mountain, New York.	Influence of acid rain on nutrient leaching and metal mobilization.
19. Wayne Robarge (North Carolina State University). Quality assurance/quality control program for analysis of water, soil, and plant samples.	Establishment of QA/QC procedures for analysis of soil, foliar, and root samples. Determination of spatial variation of selected soil properties.

Scientific Questions

2.2 What is the effect of sulfur and/or nitrogen derived pollutants alone or in combination with oxidants on red spruce and fir through the mechanism of increased leaching of foliar nutrients?

2.3 What is the effect of sulfur and/or nitrogen derived pollutants alone or in combination with oxidants on red spruce and fir morphology by the mechanism of carbon allocation and physiological processes?

Principal investigator/Project	*Outputs*
20. Michael Greenwood (University of Maine). Evaluation of the impact of atmospheric deposition on red spruce seedlings using open-top chambers.	Dose response of 0_3 on spruce seedling throughfall. Dose response of 0_3 on spruce seedling development and physiology.
21. Keith Jensen (USDA Forest Service). Impact of ozone and acid deposition on foliar leaching and growth of red spruce seedlings and spruce budworm.	Evaluation of effects of ozone and acid rain on leaching, tree growth, photosynthesis, and water relations.
22. Robert J. Kohut (Boyce Thompson Institute). Comparison of the responses of seedling and sapling red spruce exposed to ozone and acidic precipitation under field conditions.	Comparison of dose/response of 1-to-3-year-old red spruce seedlings and saplings to 3 acids and 3 ozone treatments.
23. Sandy McLaughlin (Oak Ridge National Laboratory). Interactive effects of natural and anthropogenic factors on growth and physiology of red spruce.	Characterization of principal physiological changes associated with declining spruce. Determination of effect of nitric acid vapor and hydrogen peroxide.
24. Curtis Richardson (Duke University). Effects of atmospheric deposition on red spruce: a free radical based approach.	Evaluation of ozone-induced oxygen-based radical formation in leaf tissue of red spruce.
25. John Seiler (Virginia Polytechnic Institute and State University). The impact of ozone and simulated rain on the growth, physiology, and water relations of Fraser fir.	Evaluation of changes in physiology, growth, and C allocation due to moisture stress, ozone, and acid rain. Evaluation of leaf water potential components and changes due to ozone and moisture stress.
26. Frank Thornton (Tennessee Valley Authority). A field chamber study of the response of red spruce seedlings to cloud interception and/or ozone.	Evaluation of the use of chambers for cloud exclusion studies. Results of experiments.
27. Leonard Weinstein (Boyce Thompson Institute). Effect of ozone and soil nutrient status on the physiology of photosynthesis, carbohydrate allocation, nutrition, and winter hardiness in red spruce seedlings.	Preliminary assessment of effect of ozone on physiological parameters. More complete dose-response relationships and interactions between soil nutrient status and ozone exposure.

Scientific Question

2.4 What is the effect of nitrogen compounds alone or in combination with oxidants on red spruce and fir through the mechanism of increased winter damage due to altered physiology?

Principal Investigator/Project	*Outputs*
28. Jay Jacobson (Boyce Thompson Institute). Test of the nitrogen fertilization hypothesis of red spruce decline.	Dose-response relationship of 3 acids and pH's of mist on spruce seedling growth, development, phenology, water relations, nutrient balance and biochemistry.

29. Michael H. Unsworth (Institute of Terrestrial Ecology, Scotland). Frost hardiness of red spruce in relation to forest decline and effects on red spruce of winter exposure to SO_2 and NO_2.	Evaluation of risk of frost injury based on weather data and field observations. Experimental evaluation of relationship of S, N, and acidity to physiology and biochemistry of frost hardiness. Model relating deposition to risk of frost injury.
30. Ronald C. Wilkinson (USDA Forest Service). Geographic and genetic variation in foliar cuticle development and biochemistry of epicuticular waxes of red spruce (*Picea rubens* Sarg.) in relation to winter damage and decline.	Evaluation of geographic and genetic variation of critical needle characteristics and their relationship to winter injury.
31. Mansfield M. Williams (USDA Forest Service). Mechanism of winter injury to red spruce foliage and possible complications resulting from supplemental inputs of nitrogen.	Description of winter injury mechanism and evaluation of effects of nitrogen inputs.

Scientific Question

2.5 What is the effect of sulfur and/or nitrogen derived pollutants alone or in combination with oxidants on red spruce and fir through the mechanism of disrupting reproduction or regeneration? (Not being considered by The Spruce-Fir Research Cooperative).

Scientific Question

2.6 What is the effect of sulfur and/or nitrogen derived pollutants alone or in combination with oxidants on red spruce and fir through the mechanism of altered susceptibility to insects and pathogens?

Principal Investigator/Project	*Outputs*
32. Keith Jensen (USDA Forest Service). Impact of ozone and acid deposition on foliar leaching and growth of red spruce seedlings and spruce budworm.	Influence of treated and untreated seedling on the development of spruce budworm.

The Mountain Cloud Chemistry Program

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Forests are exposed to a variety of chemicals known to be injurious to some species of trees. These chemicals include ozone and hydrogen peroxide. In this report, concentrations of air pollutants and of ions in cloud water measured by the Mountain Cloud Chemistry Project (MCCP) are analyzed to provide estimates of the frequency distribution of exposure. These frequency distributions will guide forest scientists in selecting realistic exposure levels for these chemicals in chamber studies.

During the warm months of 1986, measurements of the chemical composition of cloud water, ozone and important meteorological parameters were made at six remote sites in the eastern United States. These data were collected under one set of protocols and quality assurance procedures. This report presents frequency distributions of these data by site.

Mountain Cloud Chemistry Project

In the late summer of 1985, the Mountain Cloud Chemistry Project was organized with these objectives:

1. Determine the elevational gradients in wet and dry deposition of pollutants.
2. Determine the relative significance of various deposition mechanisms to the fluxes of chemical species into and through forest canopies;
3. Determine the frequency distributions of chemical, physical and climatic exposure.

Since some air pollutant concentrations are known to vary systematically with latitude, mountain sites were located at several latitudes, reflecting different transport distances and times from major air pollution source regions. MCCP's specific location and operating institutions are identified in Table 1. The MCCP sites were established during the late 1985-early 1986 time frame and all are currently functioning. Three of the sites are currently operating monitoring stations at several elevations; the number of monitoring stations at each mountain site is also given in Table 1. The Atmosphere Environment Service (AES) of Canada is collaborating with the United States in this project by operating similar sites at Mt. Tremblant and Roundtop Mountain in Quebec Province.

Measurements

From reviews of the research plan developed by the Eastern Spruce-Fir Research Cooperative and from earlier workshops organized by the atmospheric and forest sciences communities, there has emerged a consensus of the type of atmospheric exposure parameters that need to be measured by MCCP. These measurements are:

Gaseous chemical measurements
- ozone-continuous (hourly average)
- sulfur dioxide-continuous (hourly average)
- oxides of nitrogen-continuous (hourly average)
- hydrogen peroxide (hourly average)
- ammonia/ammonium-filterpack (weekly)
- total inorganic nitrate-filterpack (weekly)
- fine particulate sulfate aerosol-filterpack (weekly)
- sulfur sioxide-filterpack (weekly)

Aqueous chemical measurements
- cloud water chemistry (hourly)
- cloud water hydrogen peroxide (hourly)
- rain chemistry from precipitating clouds (hourly)
- precipitation chemistry, NTN (weekly)
- throughfall/stemflow chemistry (weekly)

Physical measurements
- cloud liquid water content
- presence of cloud-continuous (hourly)
- precipitation amount (hourly)

Climatic measurements (forest stress and model evaluation parameters)
- air temperature (hourly)
- wind speed and direction (hourly)
- relative humidity (hourly)
- insolation (hourly)
- barometric pressure (hourly)

Table 1.--MCCP Mountain Monitoring Sites

Mountain location	Operating institution/ principal investigator	No. of stations
Mt. Mitchell, NC	North Carolina St. Univ. Dr. Ellis Cowling	2
Whitetop Mt., VA	Tennessee Valley Authority Dr. James Meagher	1
Shenandoah Nat. Pk	University of Virginia Dr. John Sigmon Dr. James Galloway	3
Whiteface Mt., NY	SUNY-Albany Dr. John Kadlecek	3
Mt. Moosilauke, NH	Dartmouth College Dr. James Hornig Dr. Collin High	1
Howland, ME	University of Maine Dr. M. Stewart Goltz	1

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From its inception, the MCCP realized that very few of the physical and chemical measurement techniques needed were generally available. Even relatively simple procedures, as in ozone analysis or in collection of particulate samples, require modifications or adaptation when applied to the harsh, wet, mountaintop environment. In some instances, no measurement technique even existed in the commercial sector, which is the case for hydrogen peroxide and cloud liquid water content. The MCCP elected to perform certain experiments only at a single site as part of a method evaluation experiment prior to system wide deployment. Because of this necessary development activity, not all data are yet available for all sites.

The meteorological monitoring effort, conducted concurrently with the chemical and physical exposure measurements, is designed to provide a standard set of key measurements for use as inputs to the hierarchy of program objectives. In addition, the frequency of cloud exposure, distinguished by cloud type, duration and base evaluation, is presently taken manually at most sites and cloud detection will become automated in 1988. This parameter is of crucial importance in defining the extent, both in time and space, of the natural cloud water deposition process and in identifying opportunities for chemical contributions to, and subsequent impacts on, the montane ecosystems.

Table 2 summarizes the measurement status of the MCCP sites for 1986 and the future measurement plans for 1987 and 1989.

Measurement protocols during 1986 called for cloud water sampling to be performed with both active (CASC) and passive (ASRC) samplers. For subsequent years sites may sample with either sampler. Chemical analysis data from samples collected by both samplers concurrently indicated no appreciable differences between these samplers.

Network protocols called for the analysis of ozone data at all MCCP sites, and hydrogen peroxide at the Whiteface and Whitetop sites. Ozone is measured continuously with a TECO Model 49 analyzer.

Hydrogen peroxide was measured with an instrument developed by Gregory Kok based on enzyme-fluorescent technique. In addition, some sites measured other gas species under their own, site-specific protocols. These are summarized in Table 2.

Site Descriptions

MCCP research monitoring sites are all located in remote regions of Eastern North America. With the exception of Howland Forest, all sites are located on mountain summits or mountains slopes. Many of the research monitoring sites are located within forest stands. Walk-up towers were erected at forest sites to provide monitoring platforms above the forest canopy. In addition, each monitoring site has 110V AC power and many of the sites also have phone service. Access and creature comforts vary widely from site to site.

Table 3 and 4 describe the geographic and land use features of the MCCP research monitoring stations.

Table 2.--Status of Mountain Cloud Chemistry Project, 1986 and (1987-89)

Site	No. of stations	Cloud water	Instrumentation Met	Gases	Lab facilities
Mt. Mitchell	2 (3)	C,A	Complete	O,S (N)	Yes
Whiteface Mt.	2 (3)	C,A	Complete	O,S,N.H	Yes
Shenandoah	3	C,A	Complete	O	Yes
Whitetop	1	C,A	Complete	O,S,N,H	Yes
Mt. Moosilauke	1	C,A	Complete	O	No (Y)
Howland Exp.	1	None	Complete	O (S,N)	No

Key Instrumentation:

1. Cloudwater collections C = Cal Tech Active String Collector; A = ASRC.
2. Meteorological--complete package for measuring:
   Wind speed and direction, solar radiation
   Temperature, barometric pressure
   Relative humidity
   Precipitation amount
3. Gas monitors--O = ozone, S = SO_2, N = NO_X, H = H_2O_2
4. Lab Facilities - Whether or not the site has its own facilities for chemical analyses.

Table 3.--Geographic data for the MCCP Monitoring Sites

Site	Latitude	Longtitude	Elevation (m)	Canopy Height (m)	Aspect	Slope
SH1	38°38’0”	78°21’0”	1015	13	NW	0
SH2	38°38’0”	78°21’0”	716	19	W	24
SH3	38°38’0”	78°21’0”	524	24	NW	14
MM1	35°44’0”	82°16’0”	1950	17	WNW	10
MM2	35°45’0”	82°15’0”	1775	22	SSE	15
WF1	44°23’26”	73°5’34”	1483	0	0	0
WT1	36°38’20”	81°36’21”	1689	15	0	0
MS1	43°59’18”	71°48’28”	1000	10	0	0
HF1	45’11’0”	68°46’0”	65	0		3

SITE CODES:
SH = Shenandoah (University of Virginia)
MM = Mt. Mitchell (North Carolina State University)
WF = Whiteface Mt. (Atmospheric Science Research Center)
WT = Whitetop Mt. (Tennessee Valley Authority)
MS = Mt. Moosilauke (Dartmouth College)
HF = Howland Forest (University of Maine)

Table 4.--Land Use and Ecoregion Data for the MCCP Monitoring Sites

Site	Land Use	Ecoregion
SH1	National Park-Research Site	Eastern Deciduous Forest
SH2	National Park-Research Site	Eastern Deciduous Forest
SH3	National Park-Research Site	Eastern Deciduous Forest
MM1	Class 1 Wilderness (N.C. State Park)	Blue-Ridge Provenance-Boreal Montane
MM2	Class 1 Wilderness (Pisgah Nat Forest)	Blue-Ridge Provenance-Boreal Montane
WF1	Tourist Surrounded by Wild Forest	Slightly Above Krumholtz (Fir)
WT1	Recreational Use, Wild Forest	Spruce-Fir Forest
MS1	Intensive Use-Wild Forest	Spruce Fir
HF1	Commercial Forest Seed Orchard	Low-Elevation Spruce Fir

Summary of Weather Conditions During 1986 Field Season

Weather conditions during the 1986 field season contrasted sharply between the northern and southern sections of the Appalachians. The north experienced generally cool, moist conditions throughout most of the field season while the south was hot and abnormally dry.

In the north, a series of surface lows moved eastward through the Great Lakes and New England in June and July to produce abundant precipitation while, during August, the rainfall was more of the convective variety as severe thunderstorms crossed the region on several occasions. September brought above normal cloudiness while precipitation was slightly above normal in most areas. Both temperatures an rainfall were approximately normal during the month of October.

In the south, the period was marked by above normal temperatures and below normal precipitation and cloudiness as drought conditions persisted, although the area of “extreme” drought as depicted by the Palmer Drought Severity Index slowly decreased during the field season. The month of July was especially hot as a strong upper level ridge took control. The majority of precipitation during June and July was convective in nature while several synoptic scale events affected the region during August and October.

Standard Graphic Reports

A central database located at the offices of W. S. Fleming and Associates, Albany, New York, contains all MCCP standard measurement data. These standard measurement in 1986 included ozone, cloud water chemistry, and meteorological measurements. These data are stored in an ORACLE relational database on a Digital VAX 11/750. The design structure of this database is documented in the MCCP Systems Design Manual (Jan. 1987).

To facilitate more detailed investigation of the MCCP standard measurement data, two data products have been developed. The first product provides a time series representation of ozone, cloud chemistry and met data, organized together in hourly records by site and month, and distributed on floppy disks. The second product provides summary graphic reports. Examples of these standard graphic reports are found in this section (Figures 1-2).

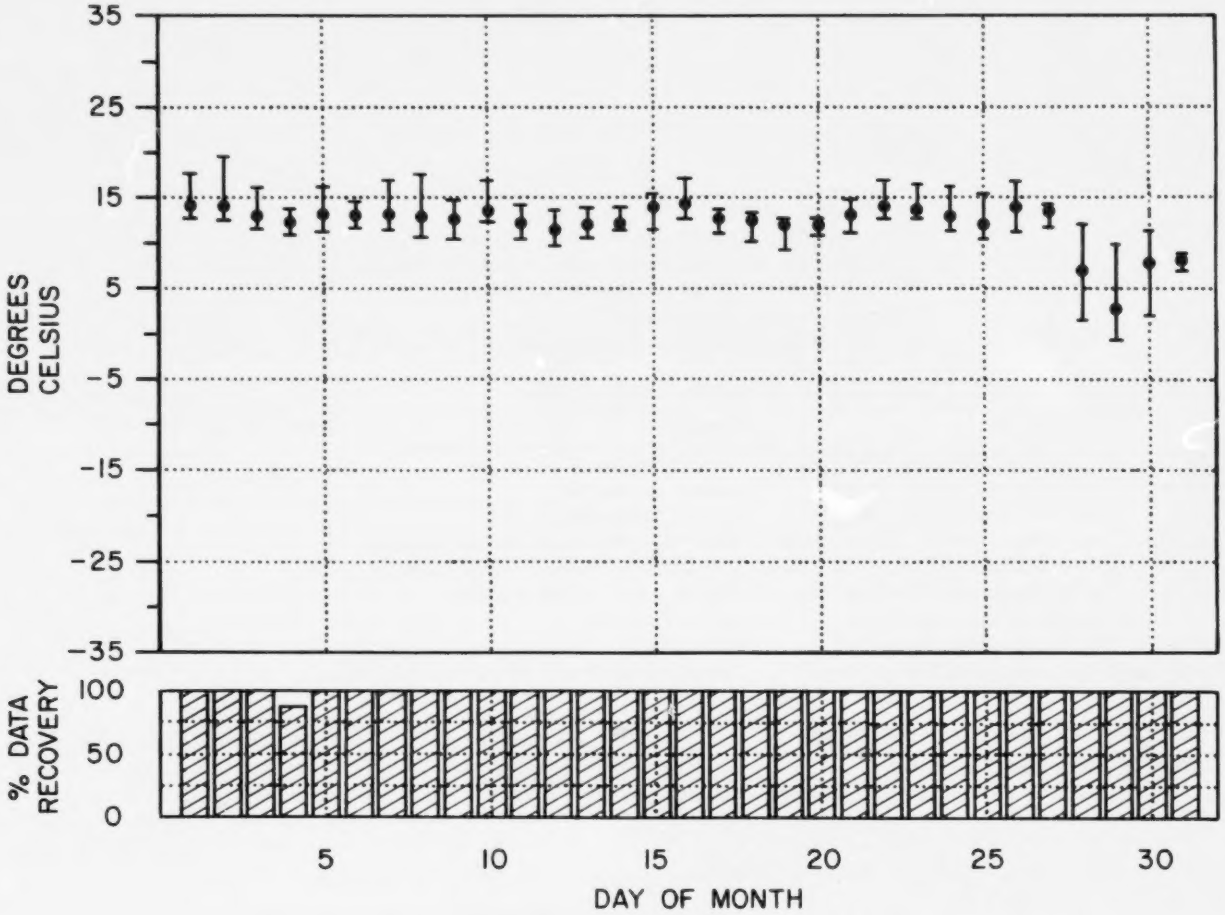

Figure 1.--Minimum, maximum, median temperature, and percent data recovery by day, Mount Mitchell Subsite 1, August 1986.

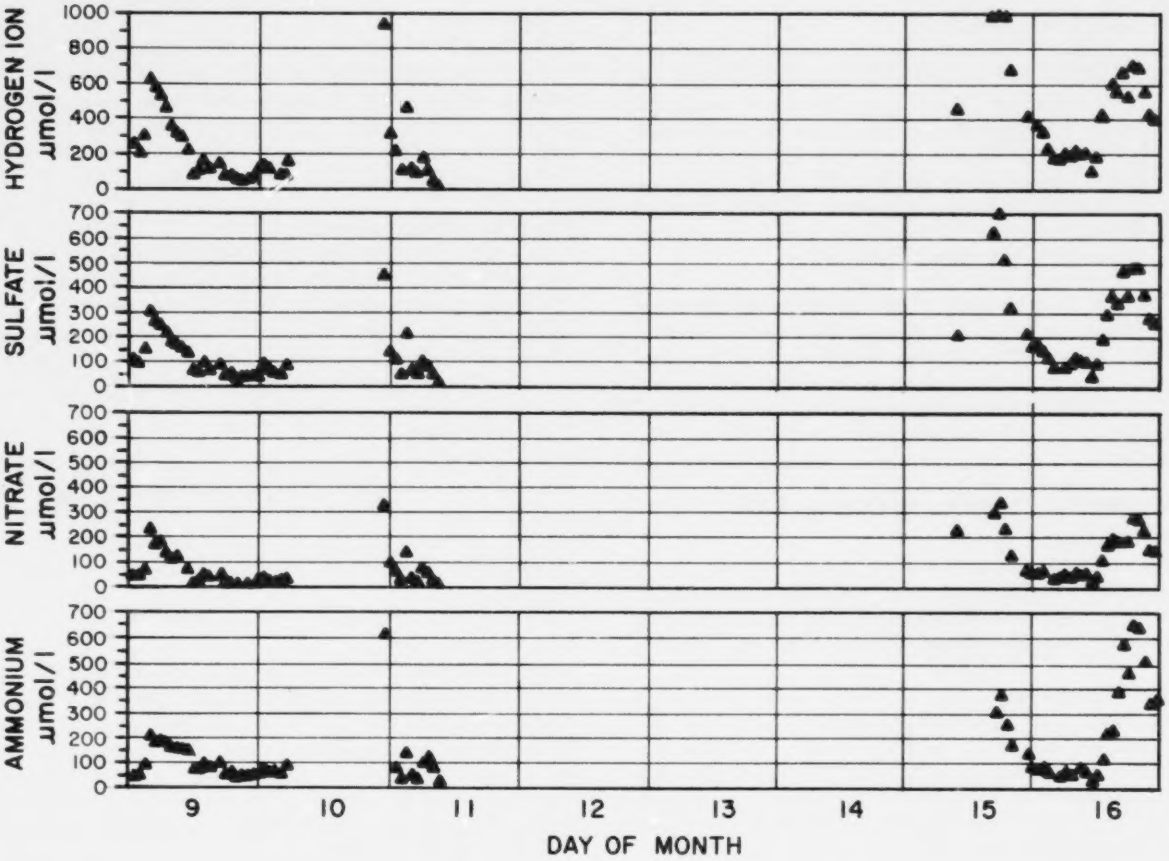

Figure 2.--Sample analysis results for hydrogen ion, sulfate, nitrate, and ammonium, Whiteface Mountain Subsite 1, August 1986.

1986 Cloud Statistics

A major objective of this project is to quantify the exposure of montane forests to the wet deposition process of cloud impaction. It has been found that cloud water deposition is a major source--and in some cases *the* major source--of moisture to high-elevation forests. Furthermore, cloud water deposition has also been found to be a primary process for acidic and other chemical substance inputs to these forest ecosystems. These moisture and chemical contributions by cloud may be a factor in the observed spruce-fir decline in the eastern United States.

This section presents some of the finding from the cloud observations taken by the MCCP monitoring network during the 1986 field season. These finding include statistics on cloud frequency, diurnal patterns, cloud base elevation and regional continuity based on nearby airport observations. A discussion on planned future work leading to the preparation of cloud atlas for the eastern U.S. mountains is also presented.

Measurement Techniques During 1986 Field Season

Techniques for measuring presence of cloud varied with site and include on-site visual observation by staff, reflectometer reading, a time-lapse video recording system, and relative humidity measurement. These techniques are summarized below.

On-Site Observation

During routine site visits and extended cloud events, site technicians were responsible for noting current weather and cloud conditions in a logbook. specific information regarding cloud type, cloud base (if visible), visibility and presence of precipitation were noted for cloud events. For noncloud periods, the absence of cloud and a description of sky conditions were noted.

Reflectometer

At Whitetop Mtn. only, the presence of cloud is sensed using an infrared reflectometer. The instrument emits a narrow beam of infrared radiation (0.9 micrometer) and senses the amount of radiation reflected back from aerosols and cloud droplets suspended in air. The reflectometer operates automatically and provides a continuous record of cloud presence data.

Video Recording System

A time-lapse video recording system was set up at a location 4.5 km north northwest of whitetop Mtn. at an elevation about 2,500 ft. less than the site elevation of 5,517 ft. The location of this system provides a clear view of the mountaintop and gives information on cloud impaction occurrence and types of clouds. The system was limited to daytime observations.

Relative Humidity

It has been found that a time series plot of ambient relative humidity is a good indicator of presence of cloud. Cloud onset is marked by a rapid rise in humidity values, followed by a relatively stable, continuous trace near the saturation point. Similarly, cloud dissipation is noted by an abrupt drop in humidity values.

Frequency of Cloud

Table 5 lists the percentage of days during the field season for which at least one cloud episode **of any duration** was observed at each mountain's summit. The values in parentheses define the number of observed cloud-days out of the total possible days for which data are available. Definition of a cloud-day was determined from documented visual observations, cloud water collection records, reflectometer values (Whitetop Mtn. Only) and relative humidity data.

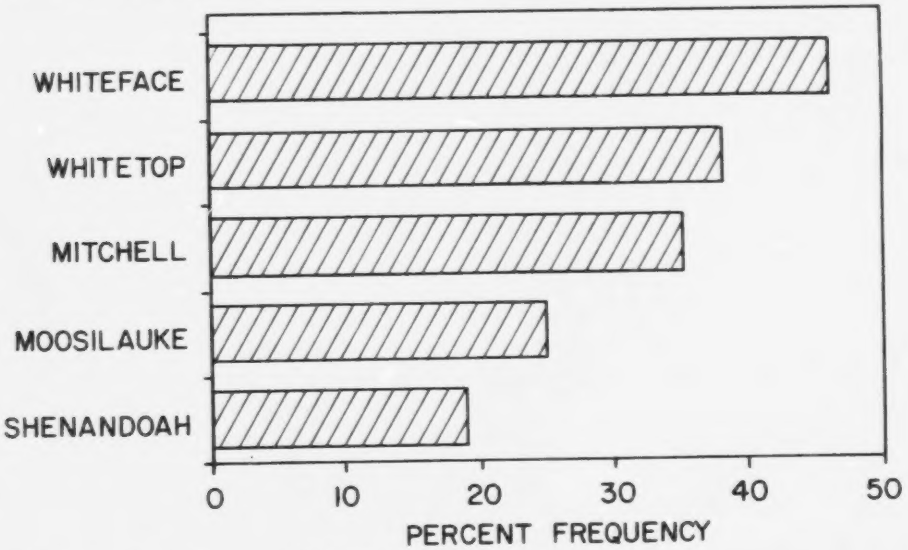

Figure 3.--Absolute frequency of cloud, 1986 field season.

Table 5.--Percent frequency of cloud-days 1986 field season

Site	Jun	Jul	Aug	Sep	Oct	Total
Mitchell	63 (12/19)	78 (18/23)	100 (31/31)	100 (30/30)	68 (21/31)	84 (112/134)
Moosilauke	--	65 (13/20)	71 (15/21)	42 (11/26)	30 (6/20)	52 (45/87)
Schenandoah	--	67 (6/9)	58 (18/31)	53 (16/30)	32 (10/31)	46 (53/114)
Whiteface	60 (18/30)	77 (24/31)	94 (29/31)	83 (25/30)	83 (19/23)	79 (115/145)
Whitetop	67 (20/30)	74 (23/31)	76 (22/29)	93 (28/30)	69 (20/29)	76 (113/149)

At three sites, Mt. Mitchell, Whiteface Mtn., and Whitetop Mtn., between 75 and 85 percent of the days experienced a cloud episode. August and September were the cloudiest months for these sites, especially at Mt. Mitchell, the highet elevation site, where a cloud event occurred every day during this period. Shenandoah and Mt. Moosilauke, which are significantly lower in elevation that the other sites, had lower incidence of cloud-days with roughly half the total days experiencing cloud.

Information on the absolute frequency of cloud impaction was limited in 1986 because instrumentation was not available at all network sites to automatically and continuously monitor actual cloud presence; only Whitetop had a continuous monitoring capability. Figure 3, which was derived largely from relative humidity data, indicates the estimated total percent of the time the summit sites were in cloud during the field season. Whiteface was the cloudiest site as a result of an unusually moist summer in the Northeast, with a frequency of 46 percent; Whitetop and Mitchell follow with between 35 and 40 percent; Moosilauke, 25 percent; and Shenandoah 19 percent. The summer of 1986 was also marked by severe drought in the southeastern states. Therefore this field season was atypical for the network in terms of "normal" weather.

Observations of cloud at Whiteface continued beyond the end of the official field season and into the winter months, showing a sharp increase in October through December (Figure 4). This trend suggests that, due to the normal southerly shift in the track of the jet stream beginning in the fall, the "cold" months of the year in general are much cloudier than the "warm" months in the northeastern United States. This is consistent with climatological records of cloudiness reported by National Weather Service Stations.

Diurnal Variations

Time-of-day variations in cloudiness at all sites showed a preference for higher frequencies during the night and early morning hours, and lower frequencies during midday. This pattern is illustrated in Figure 5. Plotted are percent frequencies of cloud for every hour during the field season at one northern and one southern site. The diurnal trend is essentially the same for both areas. The preference for nighttime clouds appears to be associated with the formation of the nocturnal inversion layer and the dynamics of the free atmosphere just above the inversion top. Concurrently, the low-level jet develops above the inversion layer, causing wind speeds to increase to their maximum a few to several hours after sunset. It is theorized that forced lifting of air as the jet approaches the mountaintops results in the observed mountain cloudiness. We have found the phenomenon to be characteristic of mountainous areas when surrounding valley airports observe clear, near calm conditions overnight. Further study into the causes of this phenomenon is planned.

At Whitetop Mtn., cloud video data were used to determine the percent occurrence of clouds (daytime) by elevation based on their observed base heights. Figure 6 illustrates the results for the November 1985-March 1986 period. Frequencies range from 11 percent at the 1,000 m (3,280) level to 38 percent at the summit.

These results show that cloud water deposition to forests occurs more frequently at night and in early morning than during the day. In addition, cloud water deposition **rates** at the night are enhanced by the observed stronger wind speeds. Sufficient data on the liquid water content and drop size distribution characteristics of these nocturnal clouds are not yet available to compare with other cloud types. Such statistics will be obtained during the 1987 field season.

Cloud Base Elevation

Direct measurement of cloud base was performed at two sites in 1986; Whiteface Mtn., using visual observations from several vantage points on the mountain; and Whitetop Mtn., using a remotely sited video camera system.

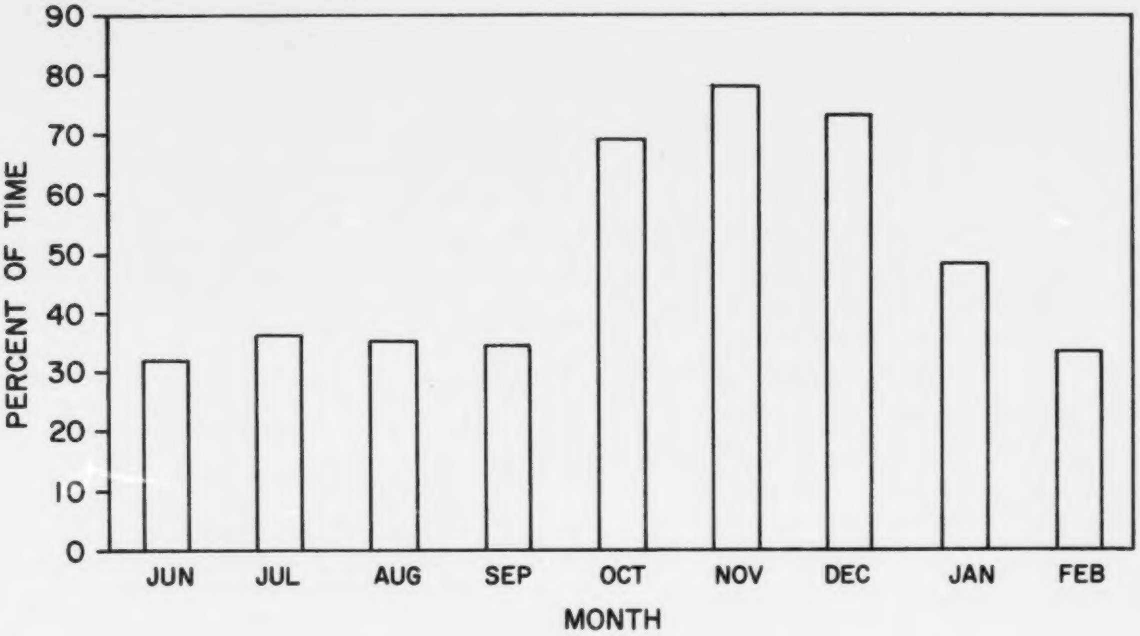

Figure 4.--Percent of time in cloud (from visual observation), Whiteface Mountain summit, 1986-87.

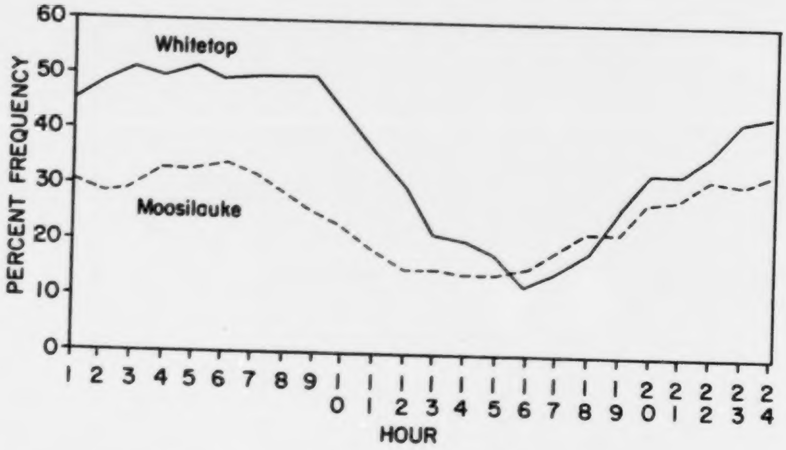

Figure 5.--Hourly cloud frequencies for Mount Moosilauke and Whitetop Mountain.

At Whiteface, 86 cloud base measurements were taken over 49 different cloud-days. Figure 7 illustrates the percentage frequency of cloud base for 500 ft. intervals. This chart shows that 14 percent of the cloud events had cloud base elevations above 4,500 ft, 22 percent between 4,000 and 4,500 ft about 27 percent between 3,500 and 4,000 ft, and so on. Cumulatively, 36 percent of the events were confined to an elevation above 4,000 ft and 76 percent were above 3,000 ft. Nearly 12 percent of the events had cloud bases below 2,500 ft.

These types of statistics will be used to support the determination of deposition gradients with altitude. Ultimately, we aim to have this information available for all mountains in the eastern United States by the end of the project.

Frequency Distributions of Hydrogen Peroxide

Hydrogen peroxide (H_2O_2) plays an important role in the acidification of cloud and rain water through participation in the aqueous phase oxidation of dissolved SO_2. This species is particularly important because oxidation by H_2O_2 is acid catalyzed, thus permitting the reaction to proceed even at low pH. Model calculations suggest that H_2O_2 or other peroxides must be present to produce cloud water pH below 3.5. Hydrogen perioxide, when applied in a simulated fog solution, has been shown to cause morphological damage to Norway spruce similar to that observed in the Black Forest. The solution H_2O_2 concentration over the 60-day experiment was approximatley 90 μm. Thus it is important to determine H_2O_2 concentrations at high elevation sites in order to evaluate direct and indirect impacts.

Hydrogen peroxide is produced predominantly in the gas phase by the reaction $HO_2 + HO_2 = H_2O_2 + O_2$. The concentration of HO_2 shows a seasonal cycle and is roughly proportional to the solar flux in the J (O_3) waveband. The photodissociation of ozone initiates a chain reaction leading to the formation of the all-important hydroxyl radical OH. The concentration of this radical is, in turn, controlled by carbon monoxide, oxides of nitrogen, hydrocarbons, and others.

The solar flux varies by a factor of 4-5 from winter to summer at 40° latitude. The concentration of OH is expected to vary accordingly (although is has never been measured). Since it takes two HO_2 to form one hydrogen peroxide molecule, it is anticipated that the hydrogen peroxide concentration varies by a factor of (4-5)2 or by a factor of 16-25 between winter and summer. Therefore, hydrogen peroxide is a **summer** phenomenon relating in a complex manner to the solar flux, more at southern latitudes and less at northern latitudes. The latitudinal differences are somewhat washed out because hydrogen peroxide can be transported over long distances like any other gases.

Hydrogen peroxide is highly soluble and will be absorbed by clouds and be wetted vegetative surfaces. It is generally accepted that hydrogen peroxide is the dominant oxidation agent in the aqueous phase independent of the acidity of the water. As long as there exist some hydrogen peroxide dissolved in water (cloud water or canopy stored water from dew, cloud/rain interception), sulfur dioxide will be absorbed from the surrounding ambient air on a stoichiometric ratio and converted to sulfuric acid. In addition, any wetted vegetative surface will absorb hydrogen peroxide from the gas phase.

Gas Phase Hydrogen Peroxide

Gas phase hydrogen peroxide (H_2O_2) measurements were made during the summer and fall of 1986 at the summit of Whitetop Mountain (1,689 m) and at Whiteface Mountain (1,625 m) over the past three years.

Frequency distributions for hourly averaged gas phase H_2O_2 data are presented in Figures 8 and 9. The summer frequency

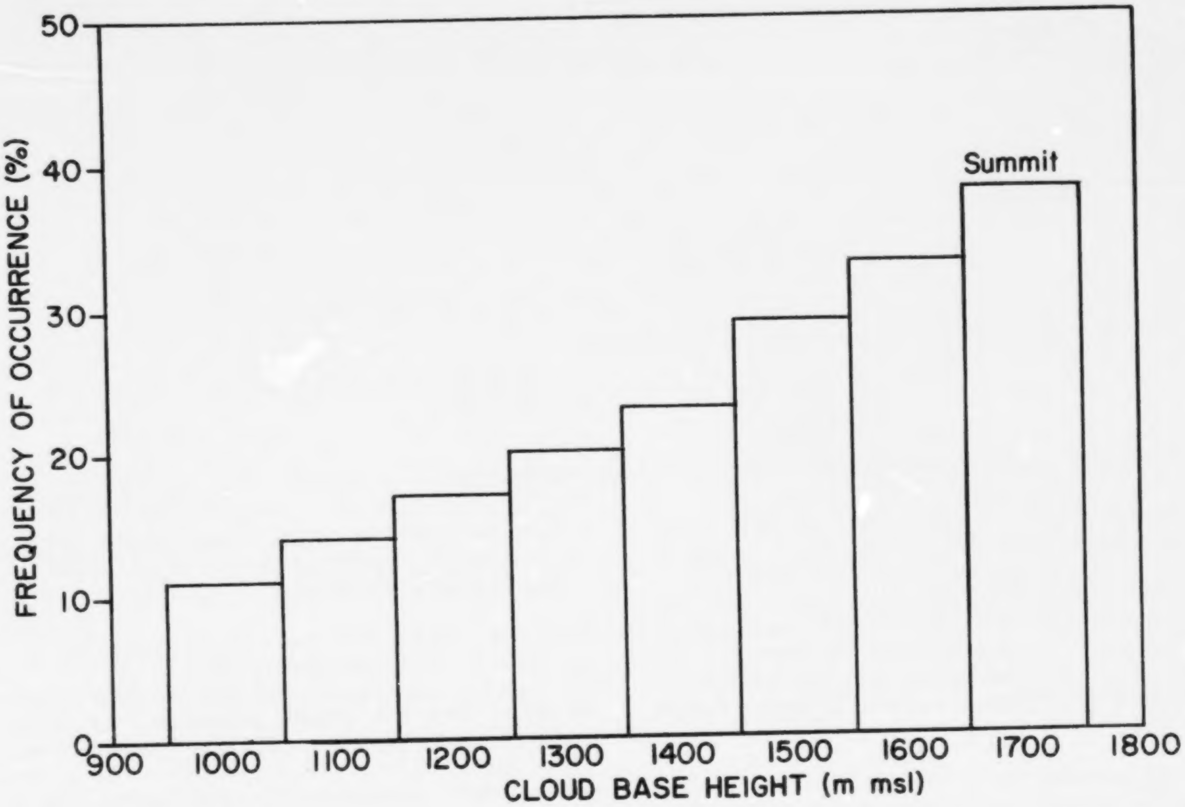

Figure 6.--Occurrence of daytime clouds by elevation, Whitetop Mountain, November 1985-March 1986.

distribution for Whiteface Mt. is skewed with a tail extending out toward the high concentrations. The summer Whiteface gaseous hydrogen peroxide mean of 0.72 ppb is clearly influenced by the high concentrations. The summer Whiteface gaseous hydrogenperoxide mean of 0.72 ppb is clearly influenced by the high concentration values (17 values greater than 2.0 ppb).

The fall distributions for Whiteface show a marked decline in high concentrations as compared with summer. The Whiteface mean is 0.18 ppb with a maximum of 0.75 ppb.

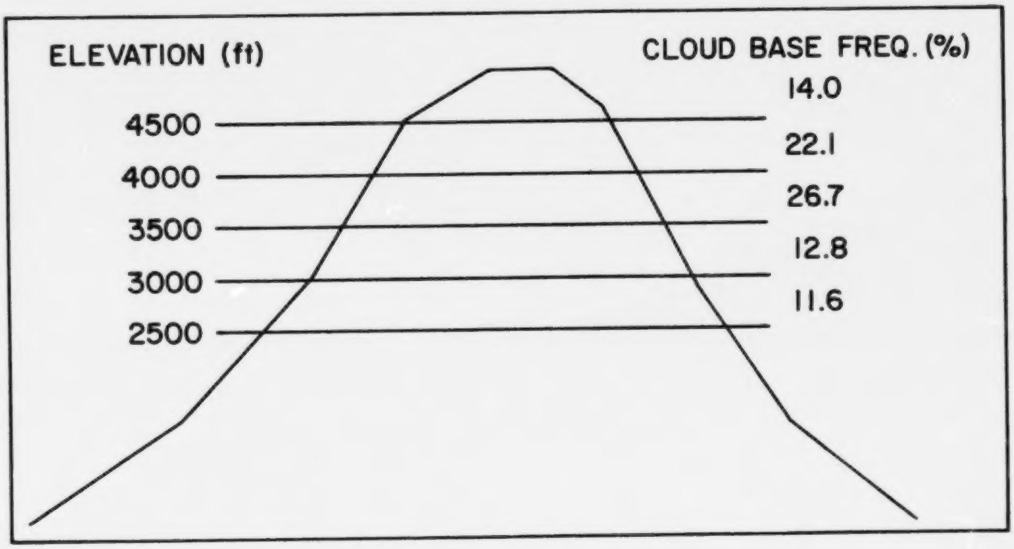
ELEVATION (ft)
CLOUD BASE FREQ. (%)
14.0
4500
22.1
4000
26.7
3500
12.8
3000
11.6
2500

Figure 7.--Cloud base frequency at Whiteface Mountain, 1986 field season.

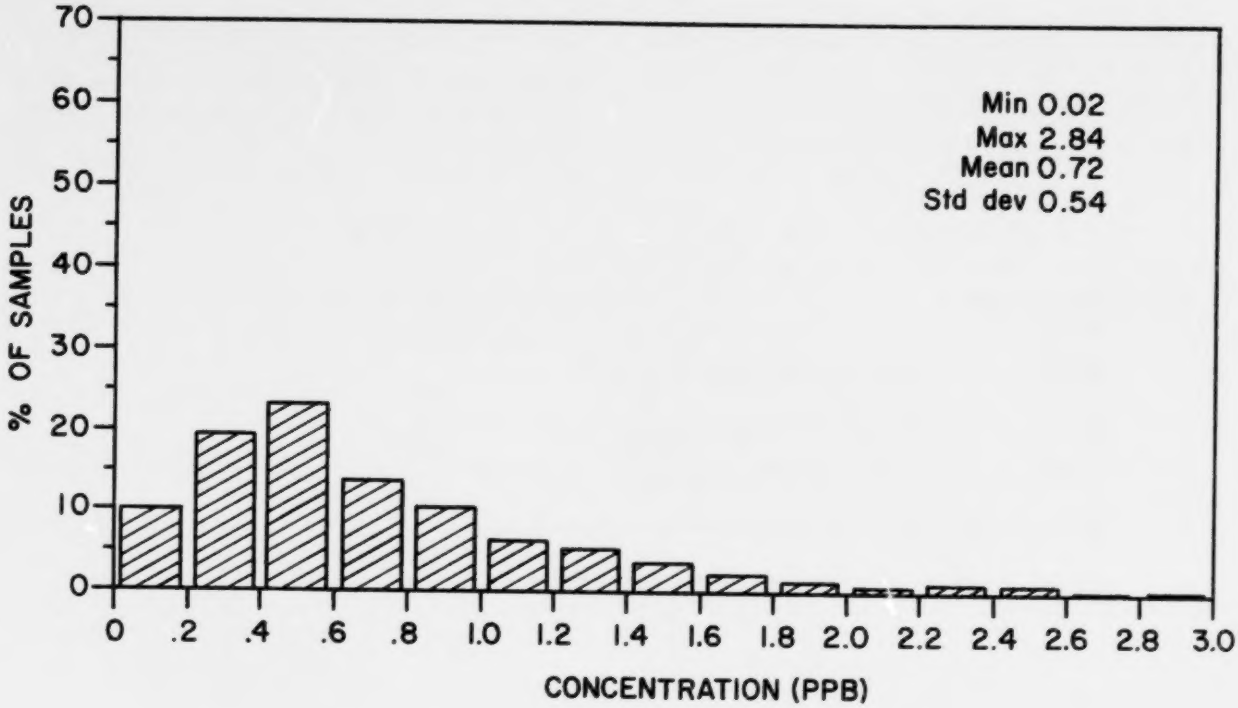

Figure 8.--Gaseous hydrogen peroxide from 424 sample values, Whiteface Mountain summit, July-September, 1986.

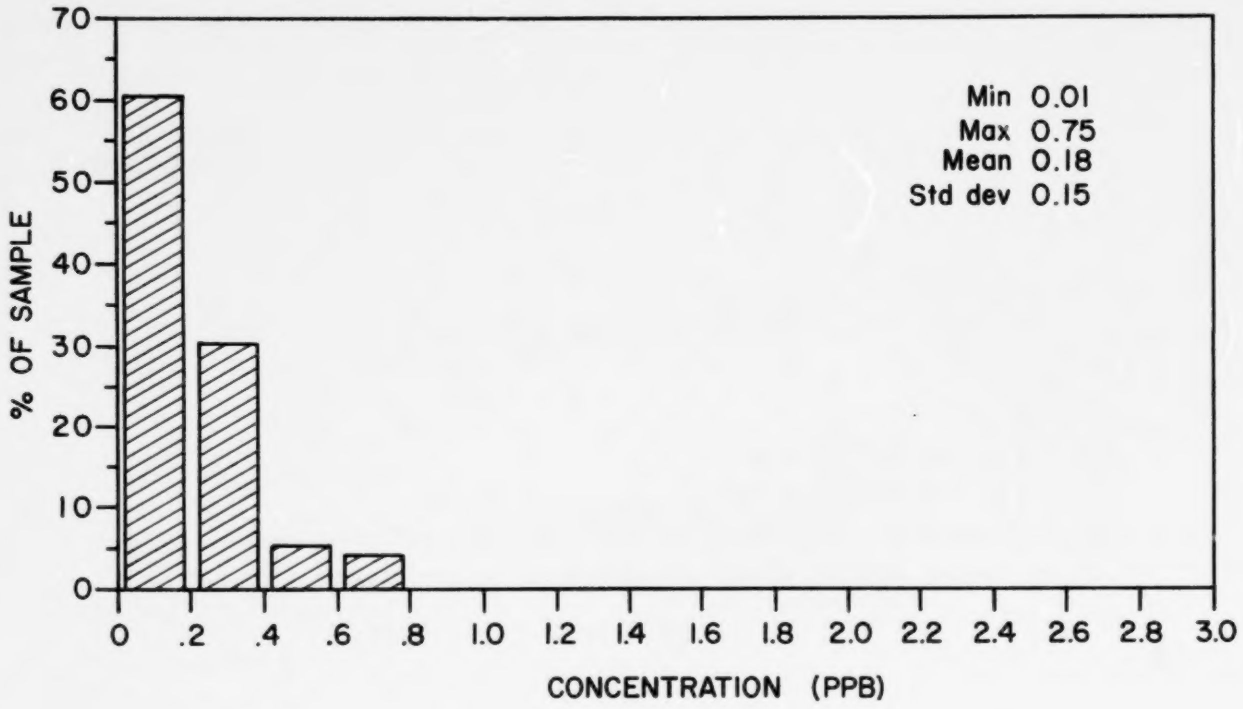

Figure 9.--Gaseous hydrogen peroxide from 76 sample values, Whiteface Mountain summit, July-September 1986.

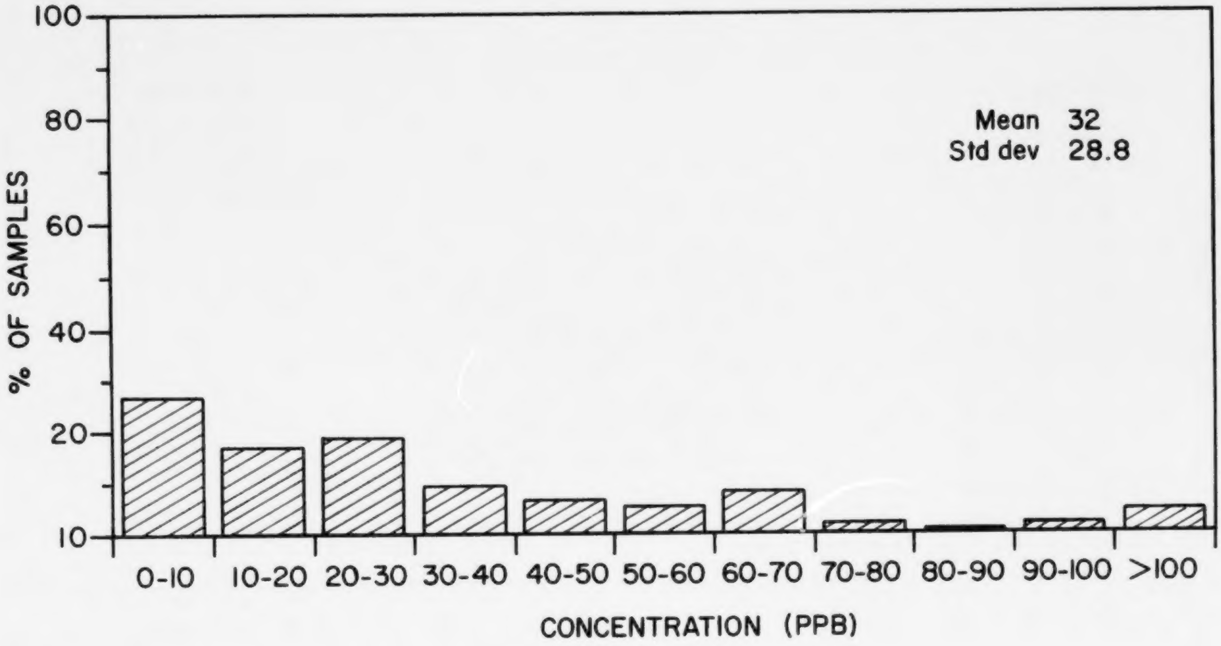

Figure 10.--Aqueous hydrogen peroxide concentrations from 150 sample values, Whiteface Mountain summit, 1985.

Aqueous Phase Hydrogen Peroxide

Frequency distributions for cloud water H_2O_2 concentrations at Whitetop for the spring, summer, and fall period have been collected. Whiteface mountain frequency distribution data are shown in Figure 10 for the summer of 1985, since considerably more data are available than for the 1986 field season.

Summary

Measurements indicate strong a seasonal dependence for H_2O_2 with highest levels in the summer and lesser concentrations measured in spring and fall. These observations suggest that high-elevation forests will be exposed to cloud water H_2O_2 levels during the summer season in excess of 100 μM and to gas phase concentrations in excess of 2 ppb.

The observed seasonal dependency in gas phases H_2O_2 is consistent with our current understanding of the chemistry of H_2O_2. The higher light intensity, water vapor, and radical precursor levels that occur in the eastern United States in the summer months would contribute to enhanced H_2O_2 formation in the atmosphere.

Frequency Distribution of Ozone

Ozone is a primary air pollutant measurement. MCCP ozone measurements began in 1986. Ozone is one of the most frequently mentioned causal agents in the forest decline problem. Ambient ozone exposures have caused physiological modifications, visual injury, and reductions in yield in agricultural crops and trees. High-concentration (episodic) exposures appear to be more important than long-term, low-concentration exposures. However, little is known about specific exposure regimes that affect trees.

It is generally recognized that the ozone concentration at any given location is the combined result of ozone originating from a number of different sources. These sources include:

- natural or "background: troposheric ozone;
- ozone generated from local anthropogenic emissions;
- ozone associated with long-range transport and accumulation in high-pressure weather systems;
- ozone formed in the urban plume downwind of cities;
- ozone injected from the stratosphere into the troposphere and transported to the surface by convective mixing.

The summer ozone life cycle is strongly influenced by synoptic weather systems. Elevated ozone levels which tend to cover large areas of eastern North America are found typically on the rear sides of anticyclones or in the warm sectors of cyclones.

The total ozone exposure in mountainous areas can be considerably higher than in nearby valley sites. This is because the ozone trapped below the nocturnal inversion layer is efficiently depleted by dry deposition and chemical reactions if other reactants are present in sufficient quantitites. Above the nocturnal inversion layer, dry deposition does not occur and the concentration of ozone scavengers is generally lower, so the ozone concentration remains nearly constant. At Whiteface Mountain, for example, the average diurnal range of ozone concentrations is within one part per billion of 40 ppb. In fact, some mountaintops experience a nighttime ozone maximum due to the absence of mixing which diluted the ozone-rich air above the inversion layer with the ozone-depleted air below the inversion layer during the day. Conversely, valley stations typically experience their peak concentrations near midday, and under strong vertical mixing conditions, maximum ozone values approach those existing aloft.

Although we assume to understand the mechanisms that explain the diurnal ozone variations, there are little data which document the diurnal variation as a function of height in the mountainous areas of the eastern United States. This is, therefore, priority research area for the MCCP. The project has begun to access and analyze available ozone data sets (e.g., SAROAD) for remote sites at different elevations, and has also established its own monitoring network. Findng on elevational gradients in ozone concentration will be presented in future report.

Measurements

The TECO Model 49 ozone analyzer is the standard network instrument used by all sites. This unit uses the ultraviolet (UV) absorption principle for ozone detection via a dual-cell UV photometer. The instrument is cyclic. In the beginning of the cycle, an air sample enters one cell and reference air (sample with the ozone catalytically converted to oxygen) enters the second cell. Detectors then measure the light intensity transmitted through each cell. During the second half of the cycle, the roles of the two cells are interchanged by appropriate switching of the solenoid valves. The instrument then determines the ozone concentration by computing the attenuation ratio of light, due to ozone absorption, from the two half cycles. The ozone concentration is directly related to the attenuation ratio. A transducer to measure changes in the temperature and pressure is directly interfaced with the microcomputer to continually correct for changes in ambient temperature and pressure.

The quality assurance protocols for ozone measurement were developed during 1986. QA protocols include zero and span checks twice weekly and calibration two times per year based on a reference standard circulated among the sites. Data validation and certification are the responsibility of the measuring facility.

There were several measurement challenges to overcome, most due to the remote and heavily forested nature of the sites. Of major concern at some sites was the distance between the analyzer, which is housed in a climate-controlled instrument shelter at ground level, and the open atmosphere above the surround forest. Due to the fact that ozone is a reactive gas sensitive to impurities within an intake manifold system, sample inlet tubes must be kept short to minimize the residence time of the air sample within the system. For most sites this issue was resolved by locating the analyzer in a small clearing open to the free atmosphere. At the Shenandoah sites, however, the lack of an adequate clearing necessitated ozone measurements be taken below the dense forest

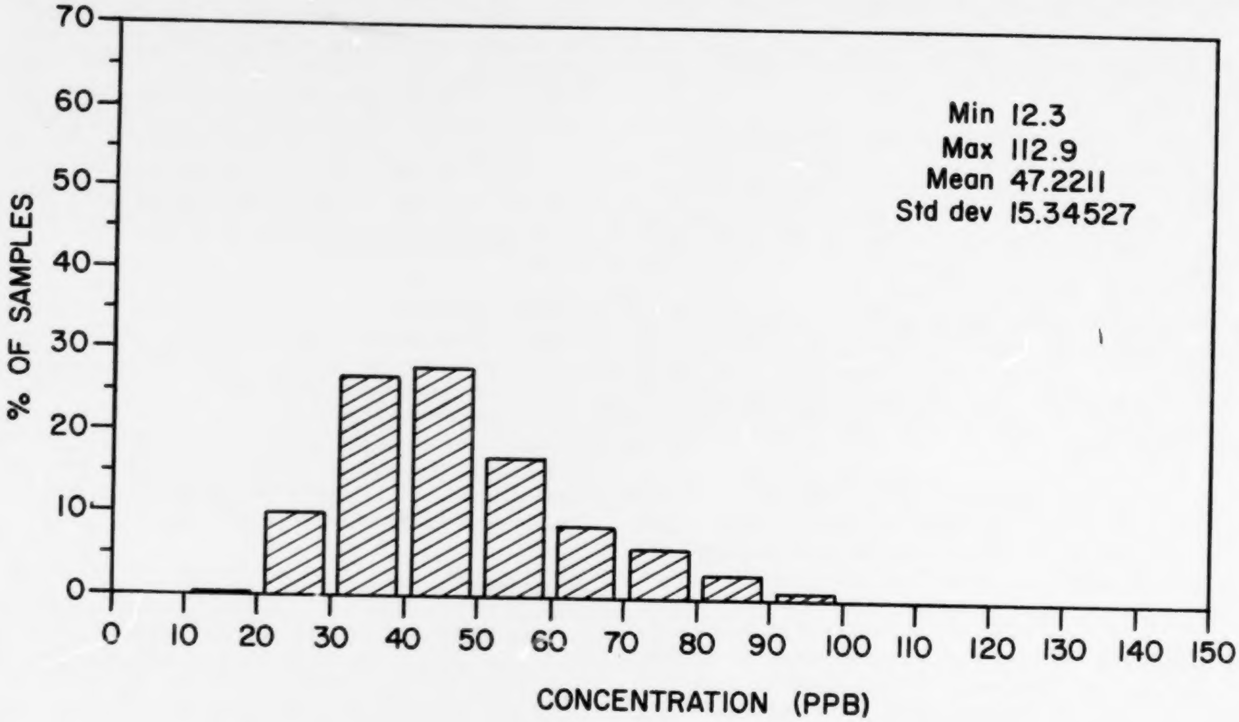

Figure 11.--Ozone concentrations from 11,098 sample values, Mount Mitchell Subsite 1, June-November 1986.

canopy. This unique data set provides insight into the ozone monitoring station at the nearby Big Meadows National Park Service (NPS) facility provides the free atmosphere ozone concentration values for comparison. In general, it has been found that ozone readings below the canopy are significantly lower in concentration that those above and, further, that below-canopy

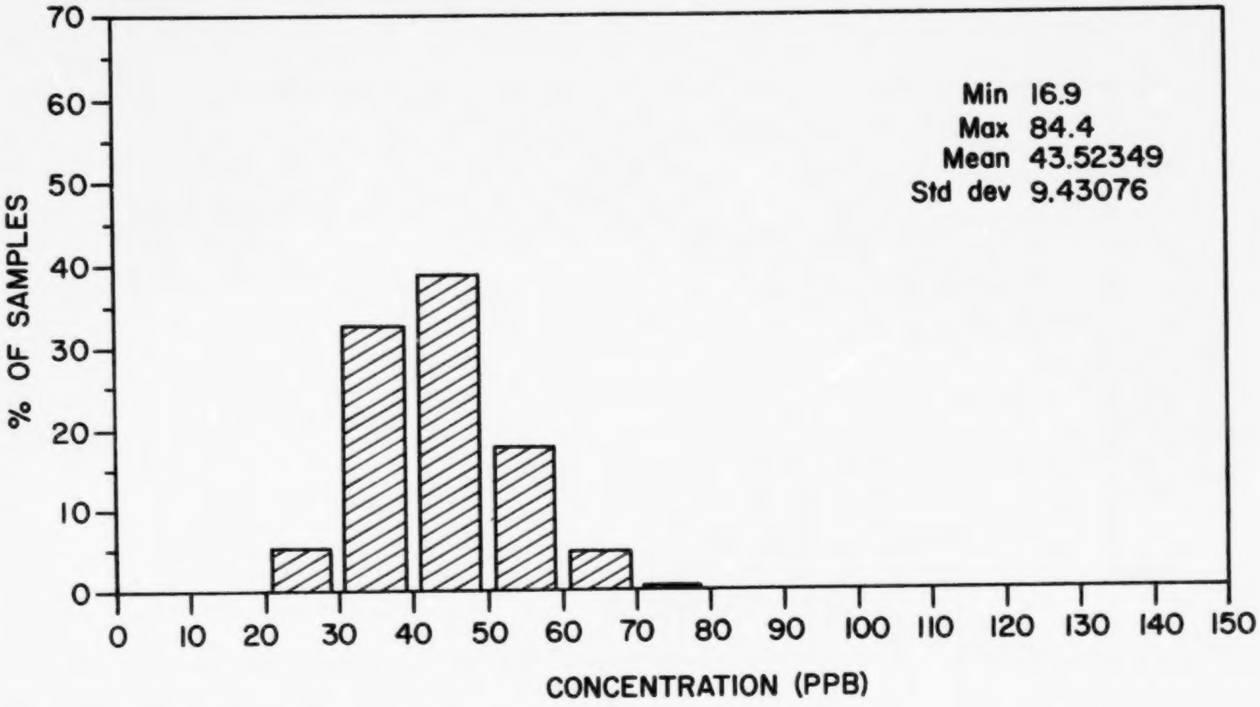

Figure 12.--Ozone concentrations from 8,720 sample values, Mount Mitchell Subsite 2, August-November 1986.

reading are strongly and positively correlated with ambient wind speed.

Presentation of Results

The following figures illustrate the frequency distributions for ozone measured in the free atmosphere. Data are presented for the following sites and time periods:

- Mt. Mitchell - Subsite 1 June-November 1986
  Subsite 2 August-November 1986
- Whiteface Mtn - July-October 1986
- Whitetop Mtn. - October, 1985-September 1986

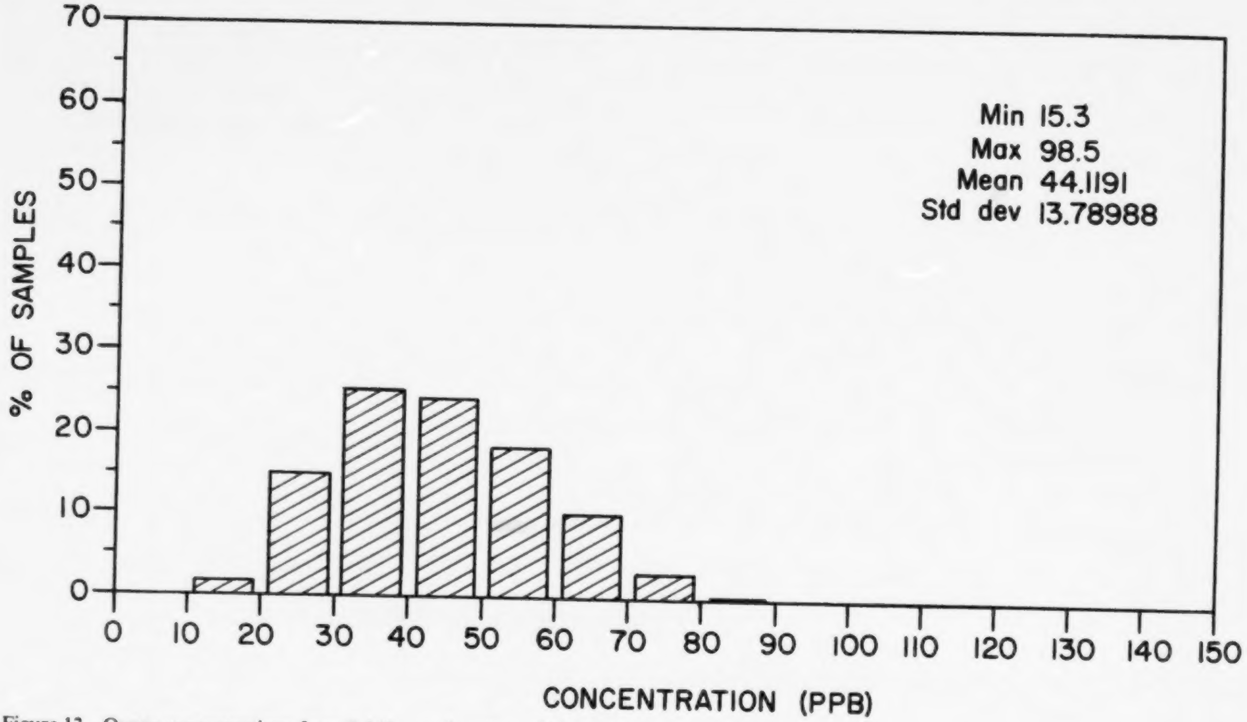

Figure 13.--Ozone concentrations from 8,263 sample values, Whiteface Mountain summit, July-September 1986.

Because identical periods of record for these sites were not available at the time this report was prepared, the ability to make site intercomparisions of ozone concentrations at this time is very limited. However, suitable records for intercomparison purposes will be available in the near future. The following discussions, therefore, pertain to the specific periods of record presented in the figures.

Figures 11 and 12 give ozone values for Mt. Mitchell subsites 1 and 2, respectively. The mean concentration for a six-month period at subsite 1, the higher elevation site at Mt. Mitchell, was 47 ppb. The maximum observed, 15-minute value was 113 ppd. At subsite 2, which began measurements later in the summer, the mean value was about 44 ppd with an 84 ppb short-term peak reading. Higher concentrations in general were measured at subsite 1, where reading above 70 ppb occurred about 10 percent of the time compared with less than 5 percent at subsite 2.

Figure 13 gives the ozone frequency distribution at Whiteface Mt. for July to September 1986. The observed mean of 44 ppb was the same as the long-term average (1978-85) for this time period. This compares with the normal annual average concentrations of 40 ppb. On a monthly basis, the highest average concentrations normally occur between April and August (46-51 ppb range), and the lowest are seen in December and January (27-29 ppd range).

Figure 14 illustrates the distribution of hourly ozone readings for the October 1985 to September 1986 period at Whitetop Mtn. The mean concentration during this 12-month period was 49 ppb with a range in hourly values from 1 ppb to 120 ppb. In summer, the mean concentration was measured as 59 ppb compared to 40 ppb in winter. As with the other high-elevation stations, ozone concentrations showed little diurnal variation.

Frequency Distributions of Ions in Cloud Water

Estimates of frequency distributions of high-elevation forest exposure to the major ions found in cloud water will help forest scientists to determine the relative significance of cloud water deposition to montane ecosystems and guide the scientists in selecting realistic exposure doses for these chemicals in controlled experiments. In this section, frequency distributions of exposure to ions in cloud water at Mountain Cloud Chemistry sites during the 1986 field season are presented.

Cloud event sampling was performed at four Mountain Cloud Chemistry sites (Mitchell, Shenandoah, Whiteface, and Whitetop) in 1986. All sites followed a standard network sampling protocol which called for the collection of cloud water at hourly intervals from the beginning to the end of a cloud event (a collectible cloud event being defined as the period of time the site was in cloud). All reported events lasted at least one hour, but duration varied greatly (up to three days) among events and among sites.

Two different cloud water collectors were used for concurrent hourly sampling during 1986. Both collectors operate on the principle of impaction of cloud water droplets on strings to collect the sample. The difference is that one, the active (Cal Tech Active String Collector, CASC) pulls air across the string using a fan, while the passive (ASRC) collector relies an ambient air flow. The two collectors were operated simultaneously to determine what differences, if any, would be found in the chemical composition of cloud water collected. The ultimate goal was to determine whether either collector could be used without biasing the ion chemistry results.

Each hourly cloud water sample collected was weighed and analyzed for pH in the field. Samples were then shipped to a laboratory where they were analyzed for major cations (hydrogen ions (as pH?, ammonium, potassium, sodium, calcium, and magnesium), anions (sulfate, nitrate, and chloride), and conductivity. All sites sent a portion of the samples they collected to the network central analytical laboratory (CAL, at Illinois State Water Survey). All frequency distribution results are based on the analyses performed at the central laboratory only in order to assure their comparability.

Comparison of Active and Passive Collector Chemistry Results

Figures 15 through 18 represent frequency distributions of hydrogen, sulfate, nitrate and ammonium ions found in cloud water samples collected concurrently using the active and passive collectors at Whiteface Mountain Summit in 1986. These results show very similar distributions for all four ions analyzed, with differences in mean ion concentration values of 7 percent or less. This direct comparability of chemistry results has led the network to leave the choice of which collector to use to the discretion of each site director in 1987.

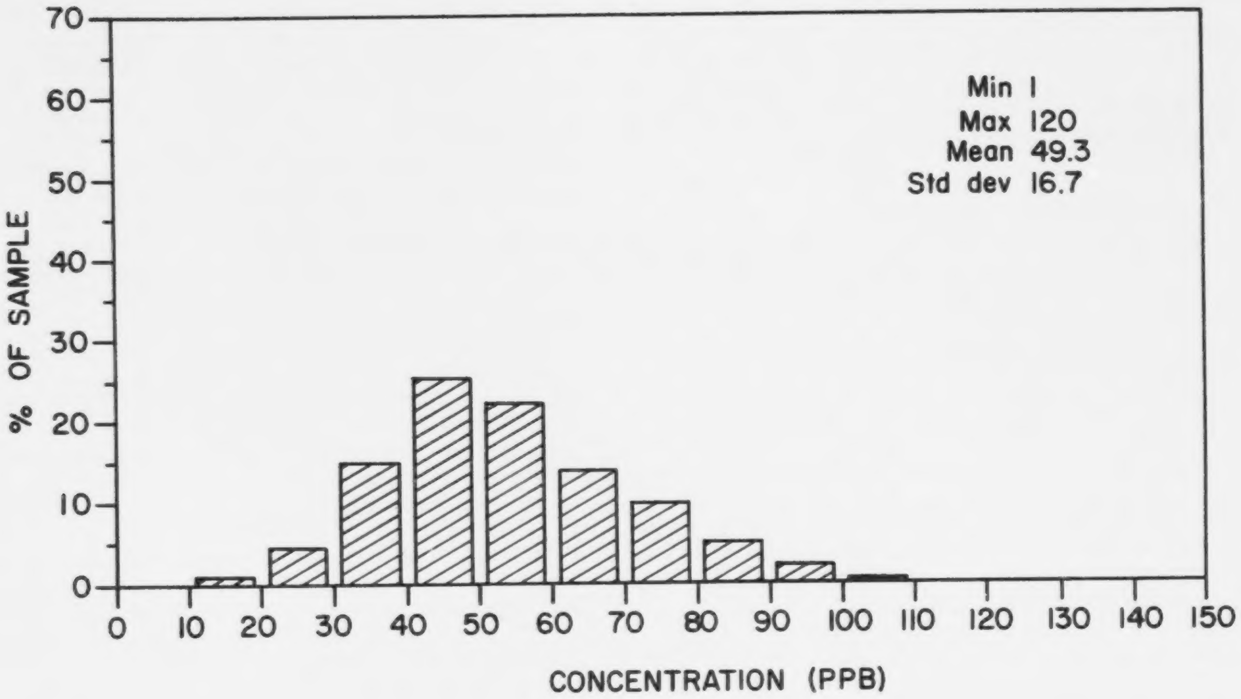

Figure 14.--Ozone concentrations from 7,479 sample values, Whitetop Mountain summit, October 1985-September 1986.

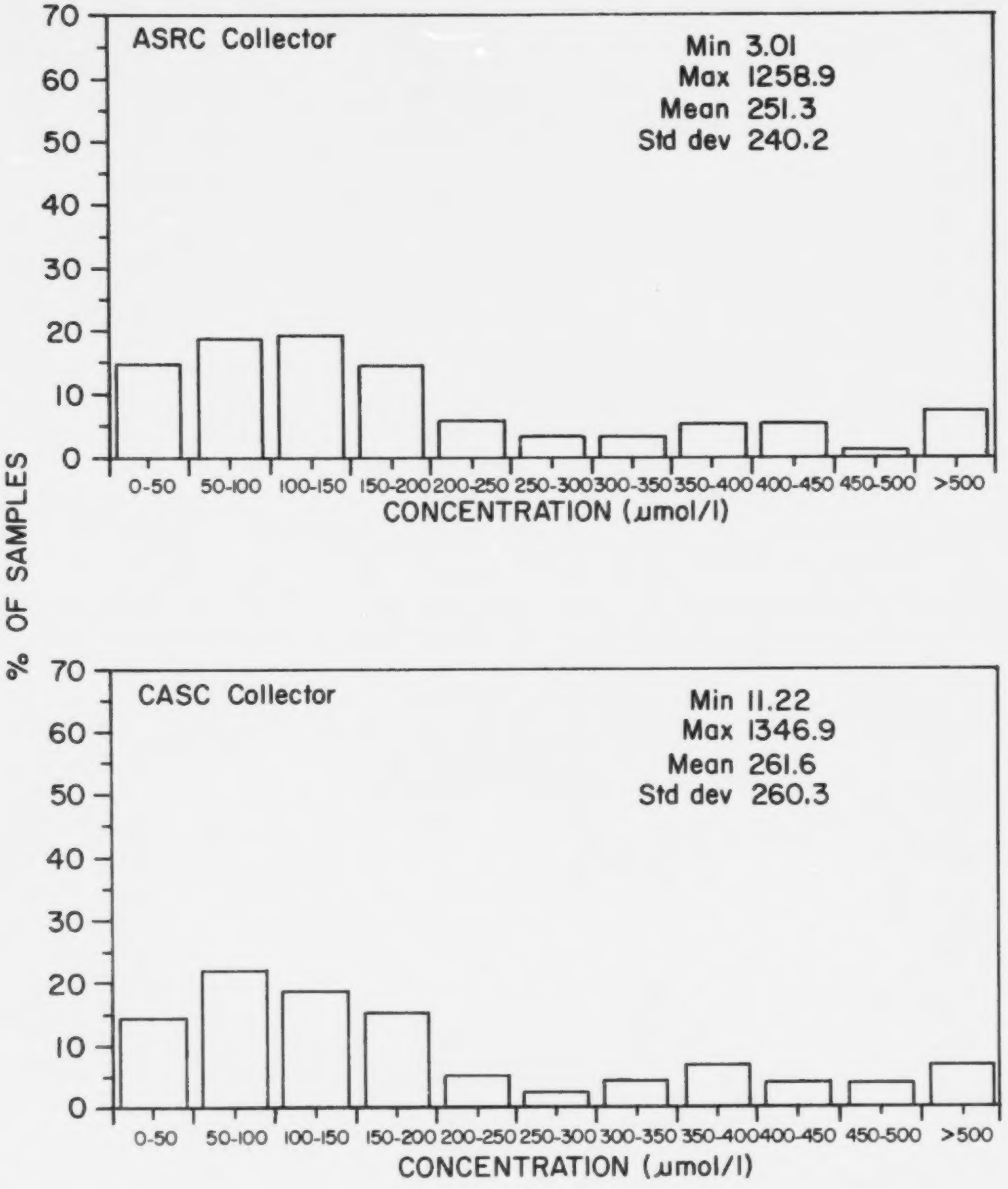

Figure 15.--Comparison of frequency distributions for hydrogen ion concentrations (167 cloud water samples from ASRC and CASC collectors, Whiteface Mountain summit, 1986.

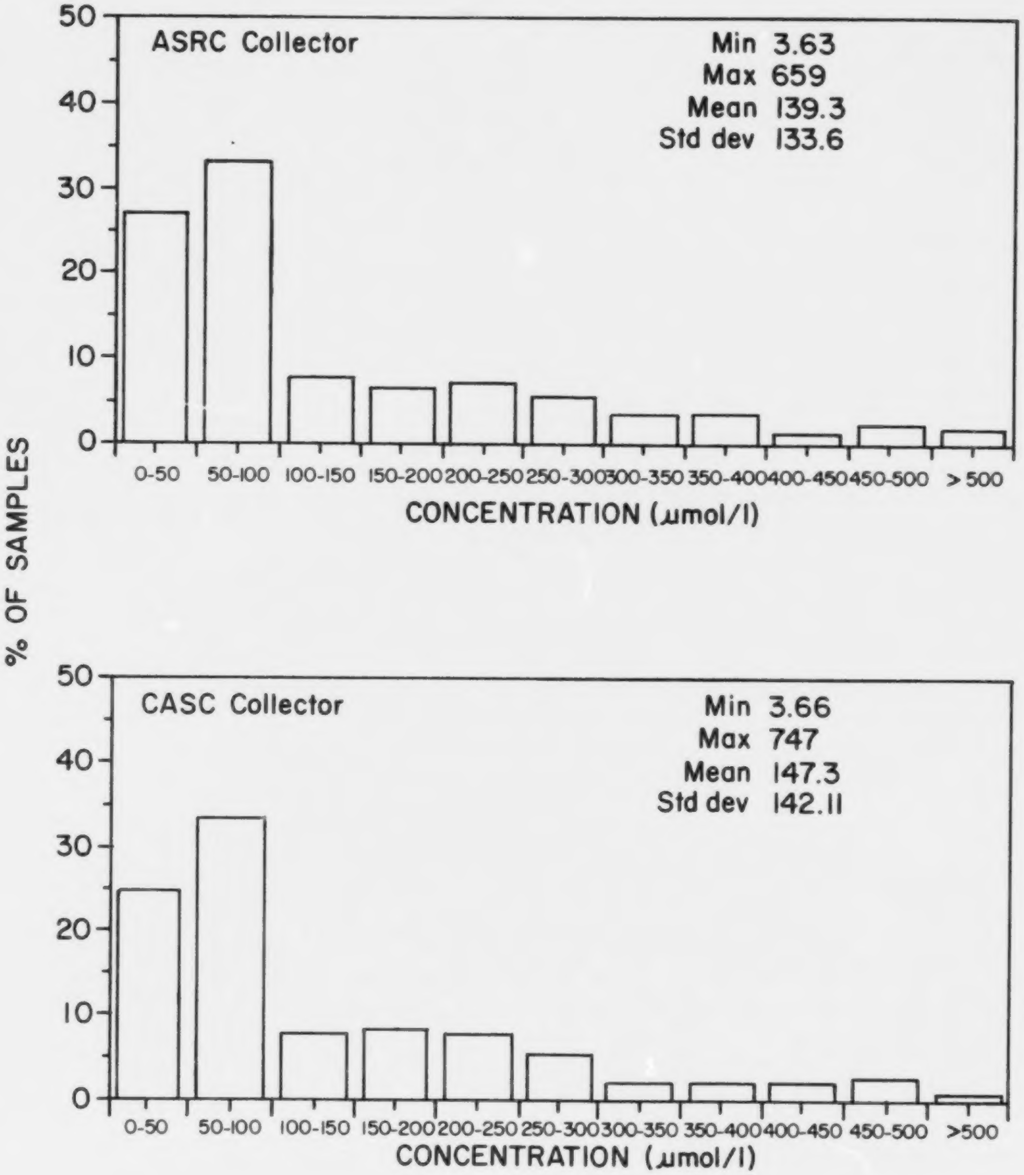

Figure 16.--Comparison of frequency distributions for sulfate ion concentrations (167 cloud water samples) from ASRC and CASC collectors, Whiteface Mountain summit, 1986.

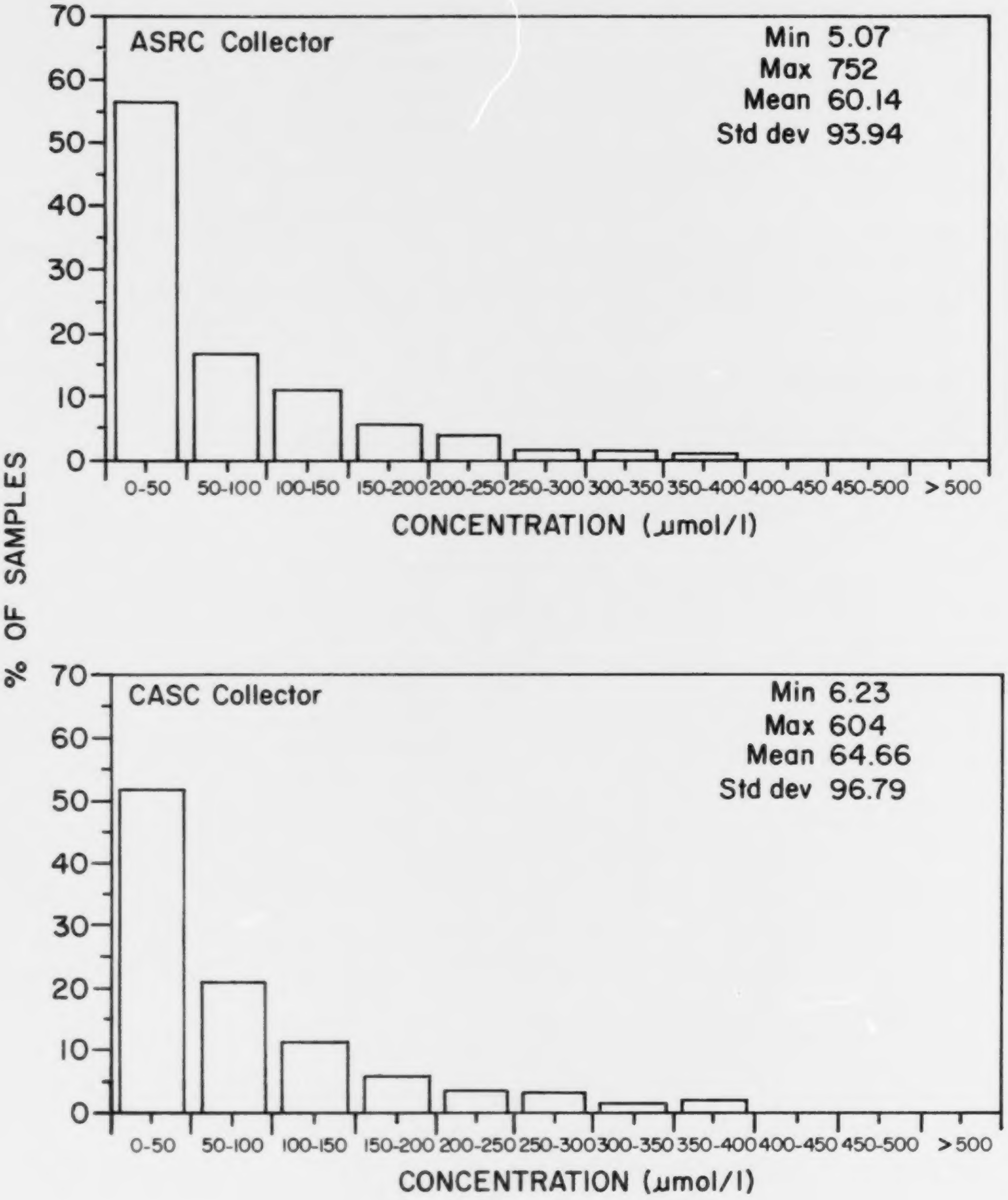

Figure 17.--Comparison of frequency distributions for nitrate ion concentrations (167 cloud water samples) from ASRC and CASC collectors, Whiteface Mountain summit, 1986.

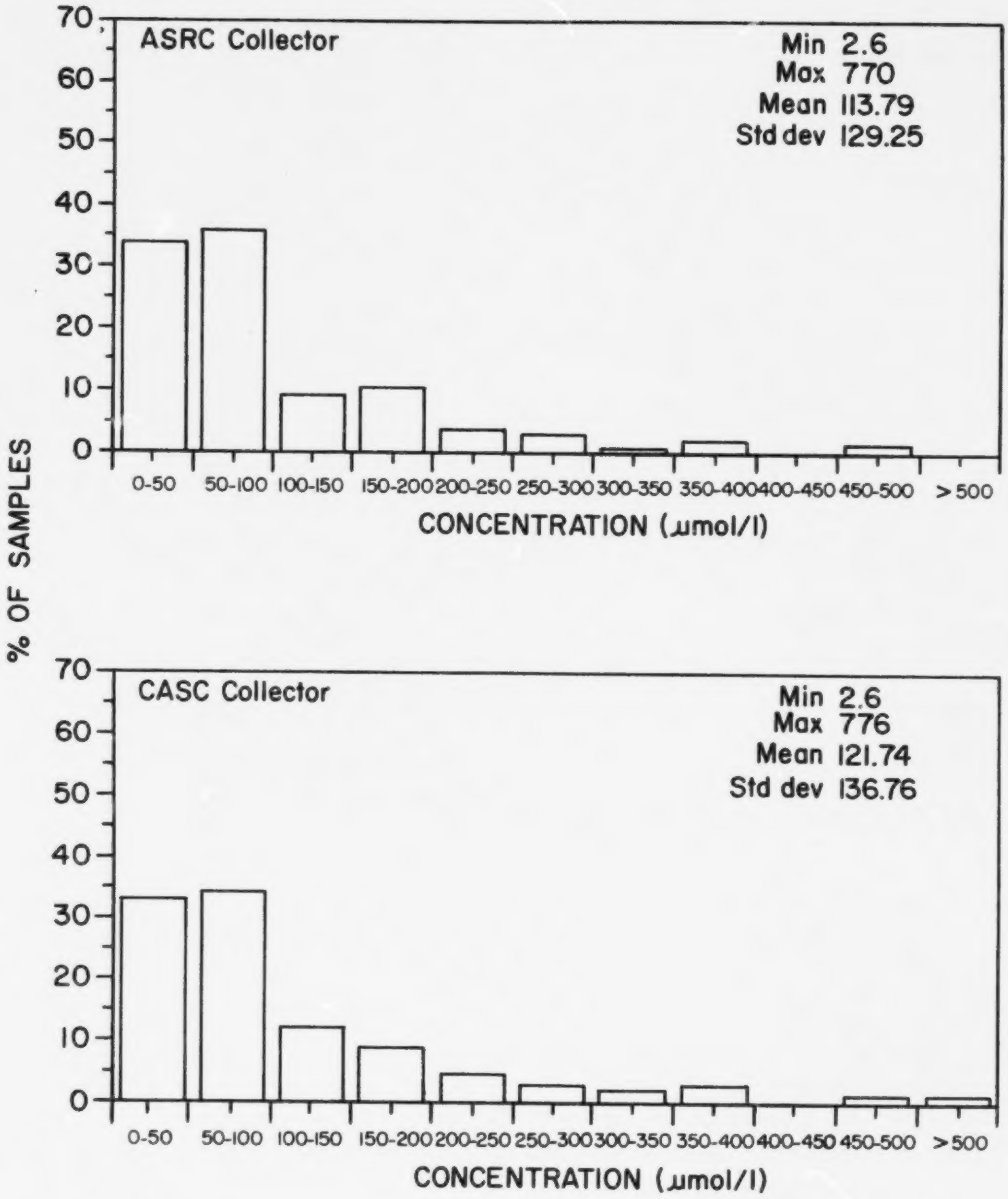

Figure 18.--Comparison of frequency distributions for ammonium ion concentrations (167 cloud water samples) from ASRC and CASC collectors, Whiteface Mountain summit, 1986.

Frequency Distribution Results

Frequency distributions of hydrogen, sulfate, nitrate and ammonium ion concentrations found in cloud water samples collected at the summit of the four Mountain Cloud Chemistry sites are presented in Figures 19 through 34. The distributions for each site are based on samples collected with the more frequently used collector, which was the passive (ASRC) collector at all sites except Whitetop Mountain. The distributions include all samples collected over the entire field season at each site which passed the data validation criteria outlined in the MCCP System Design Manual (W. S. Fleming Data Management Center, 1986). As mentioned before, only results from samples analyzed at the CAL have been included.

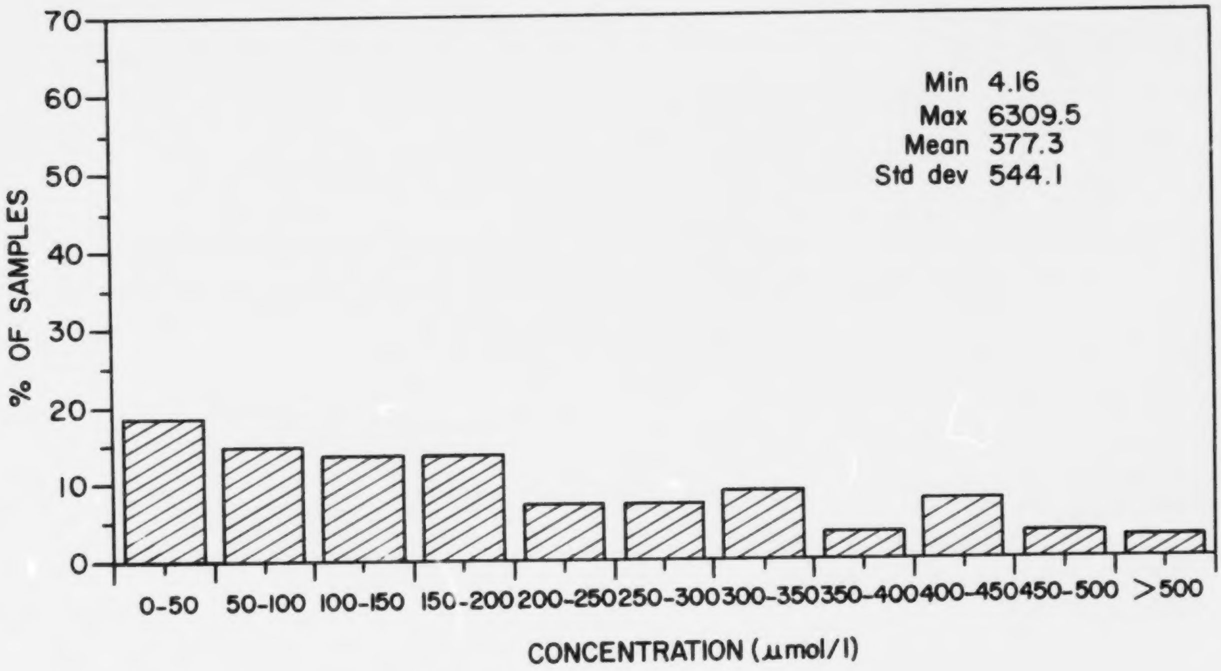

Figure 19.--Hydrogen ion concentrations from 321 cloud water samples (ASRC collector), Mount Mitchell summit, 1986.

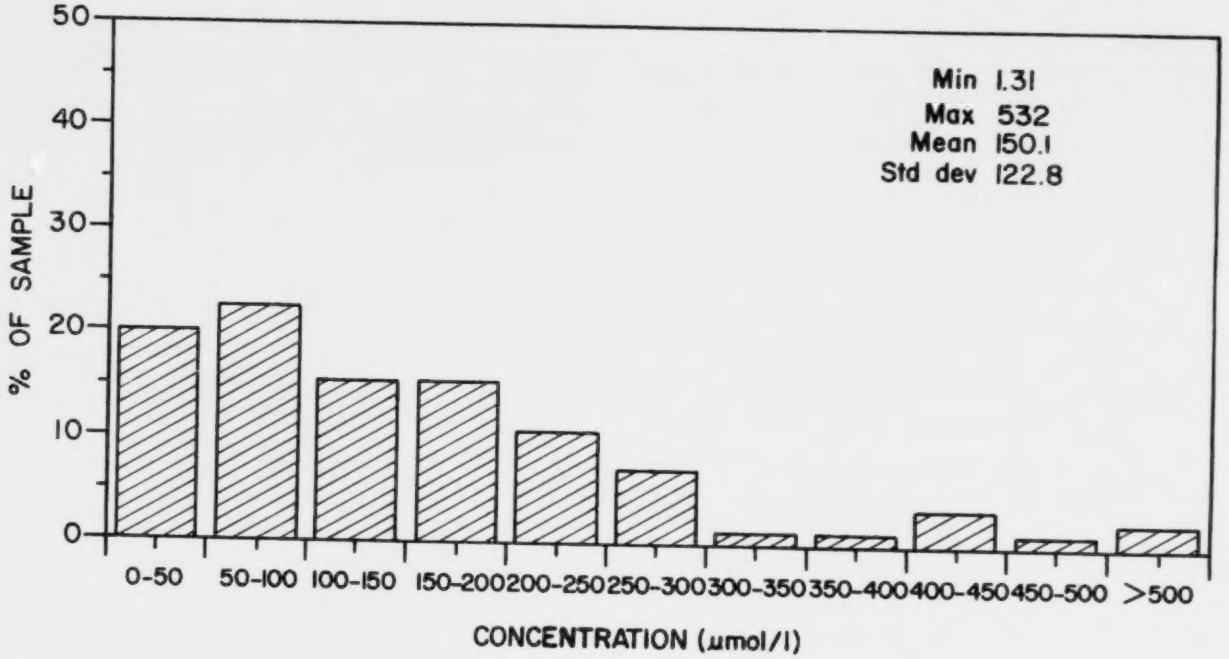

Figure 20.--Sulfate concentrations from 85 cloud water samples (ASRC collector), Mount Mitchell summit, 1986.

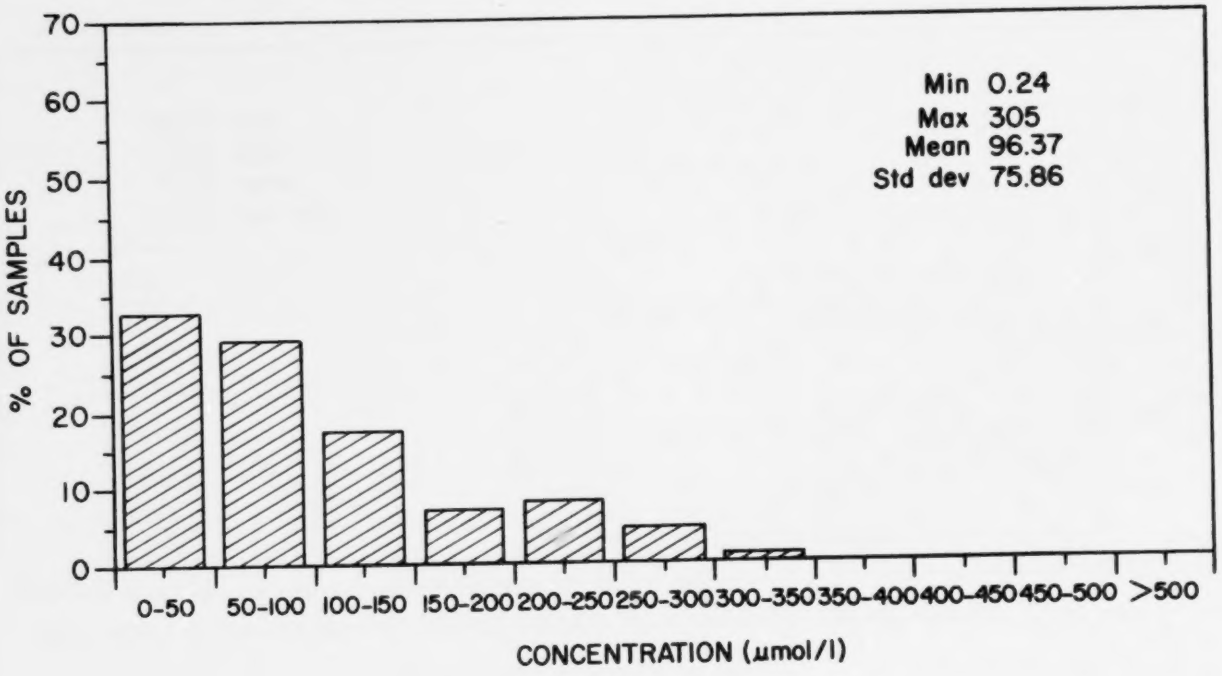

Figure 21.--Nitrate concentrations from 86 cloud water samples (ASRC collector), Mount Mitchell summit, 1986.

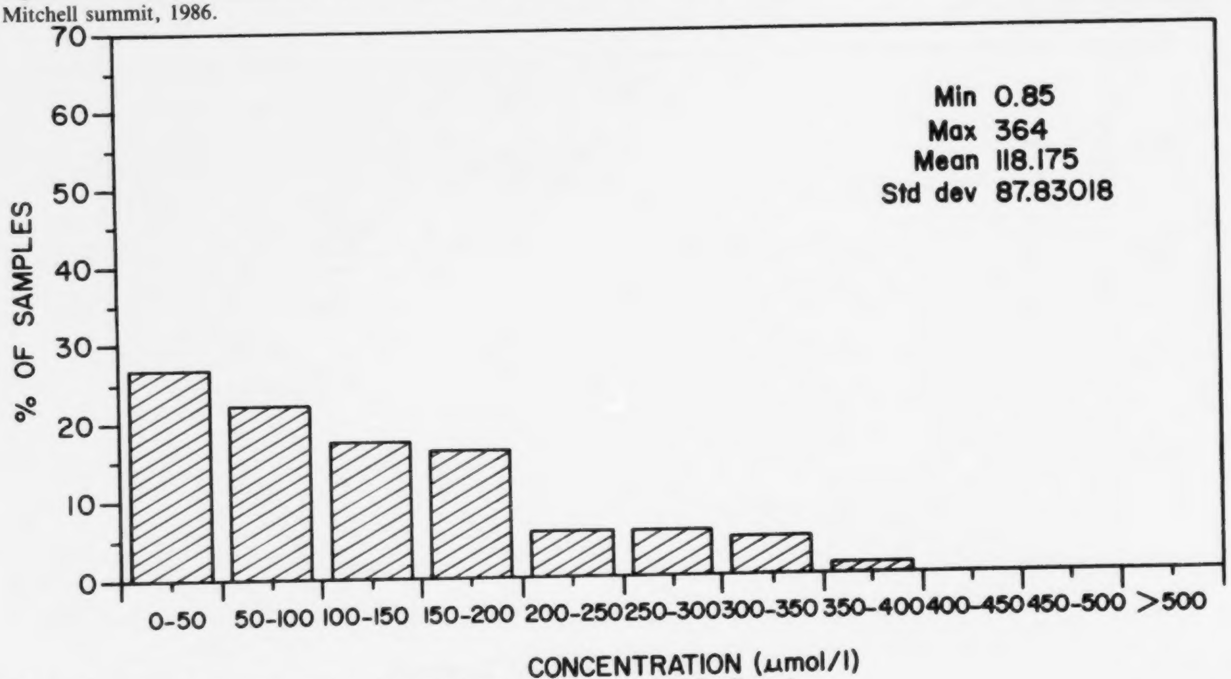

Figure 22.--Ammonium concentrations from 86 cloud water samples (ASRC collector), Mount Mitchell summit, 1986.

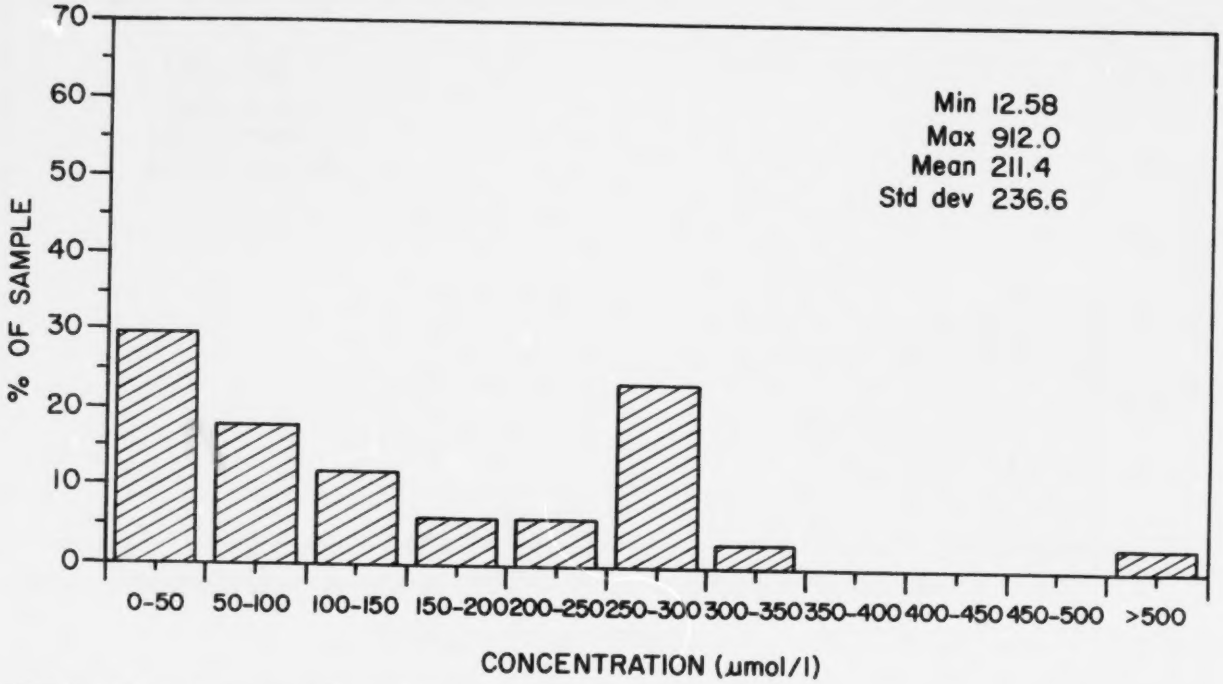

Figure 23.--Hydrogen ion concentrations from 38 cloud water samples (ASRC collector), Shenandoah Pinnacle, 1986.

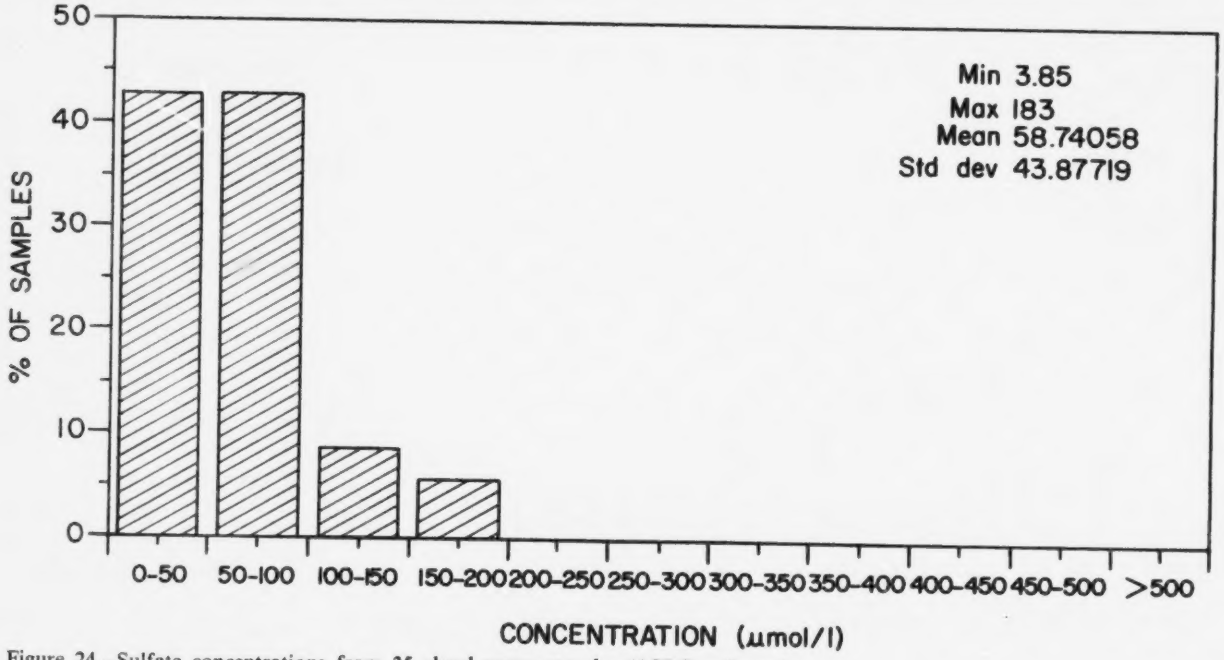

Figure 24.--Sulfate concentrations from 35 cloud water samples (ASRC collector), Shenandoah Pinnacle, 1986.

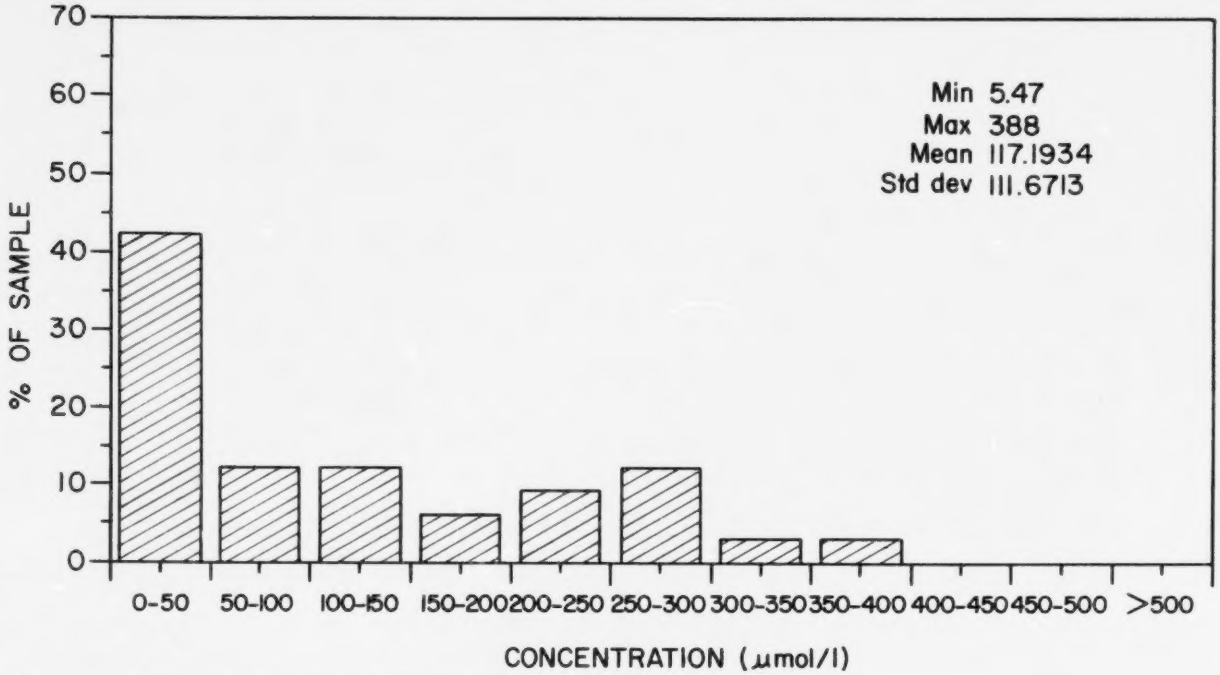

Figure 25.--Nitrate concentrations from 33 cloud water samples (ASRC collector), Shenandoah Pinnacle, 1986.

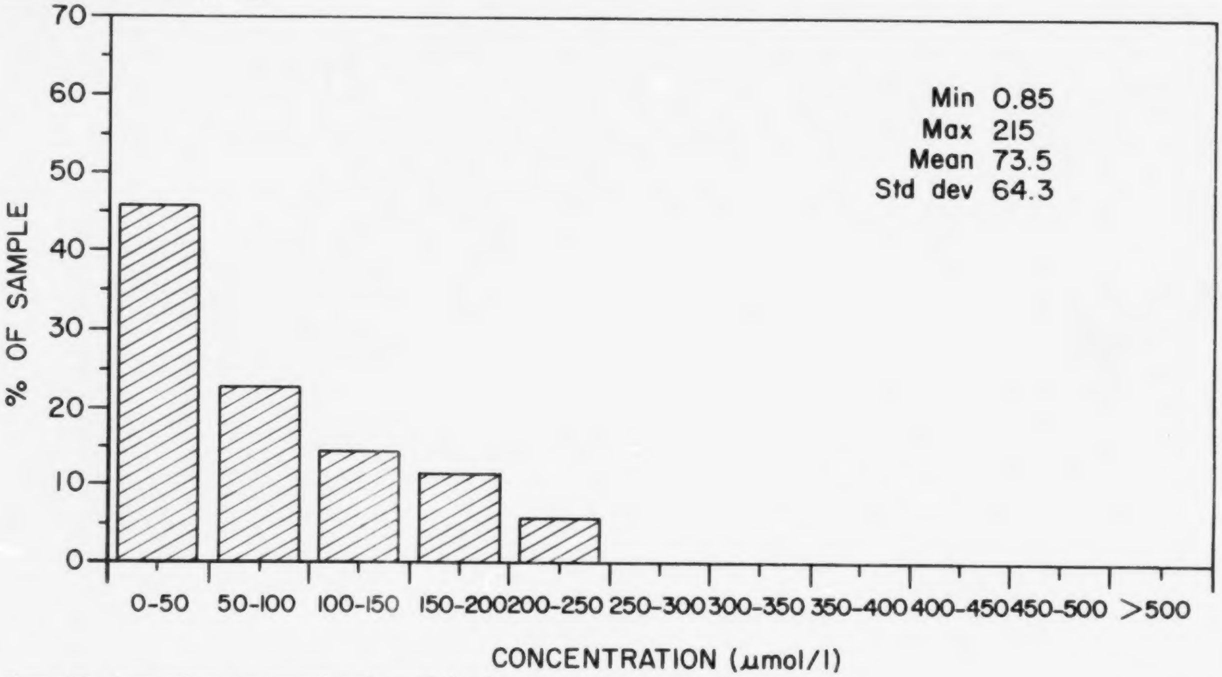

Figure 26.--Ammonium concentrations from 35 cloud water samples (ASRC collector), Shenandoah Pinnacle, 1986.

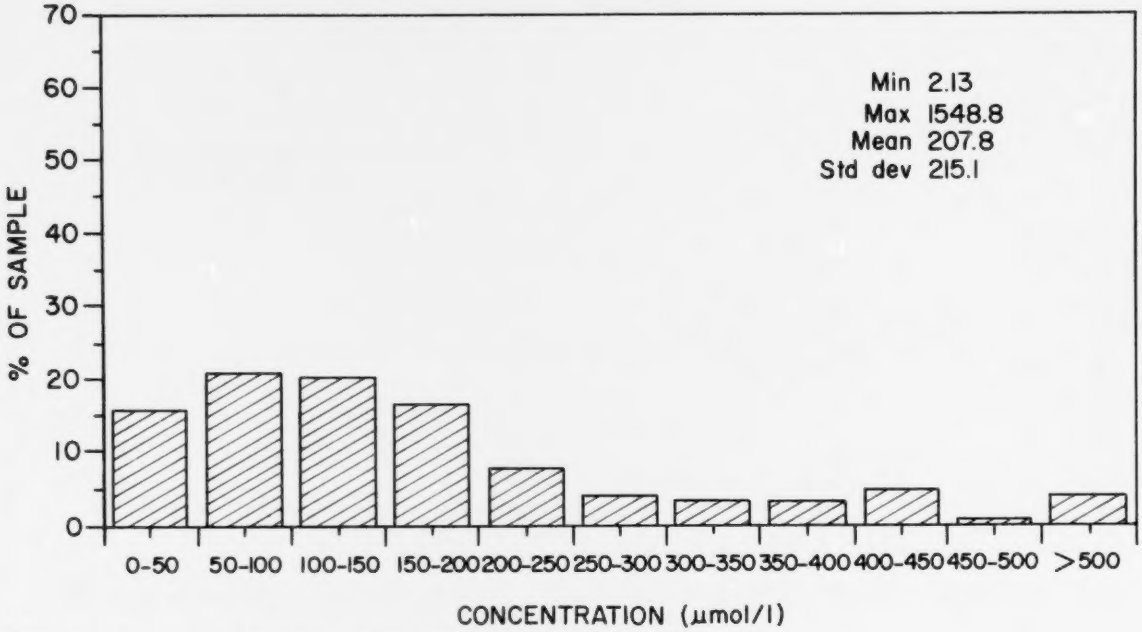

Figure 27.--Hydrogen ion concentrations from 329 cloud water samples (ASRC collector), Whiteface Mountain summit, 1986.

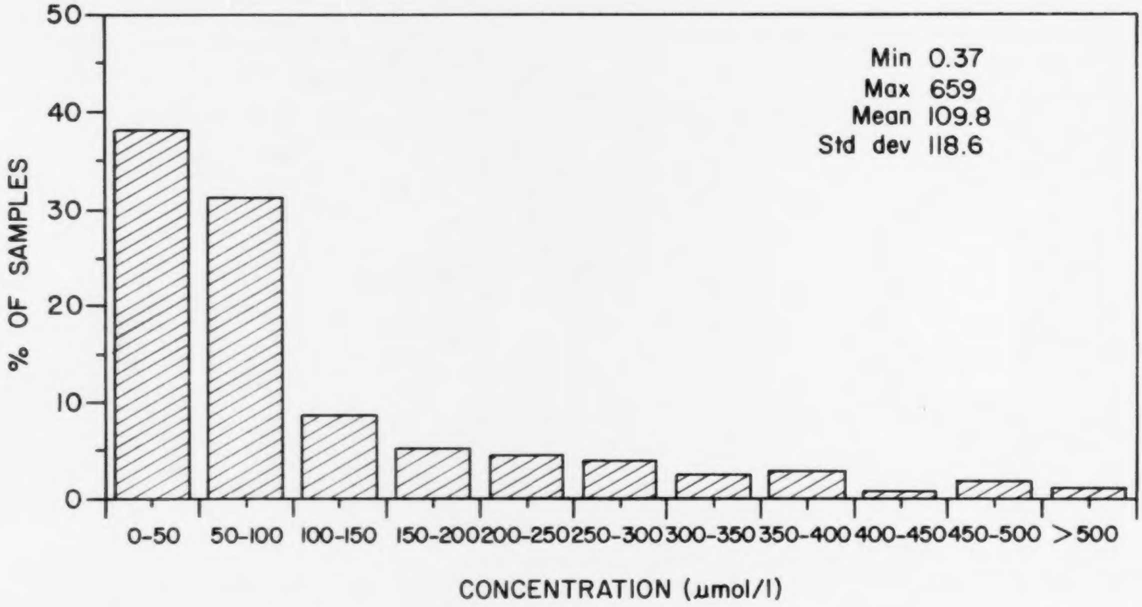

Figure 28.--Sulfate concentrations from 290 cloud water samples (ASRC collector), Whiteface Mountain summit, 1986.

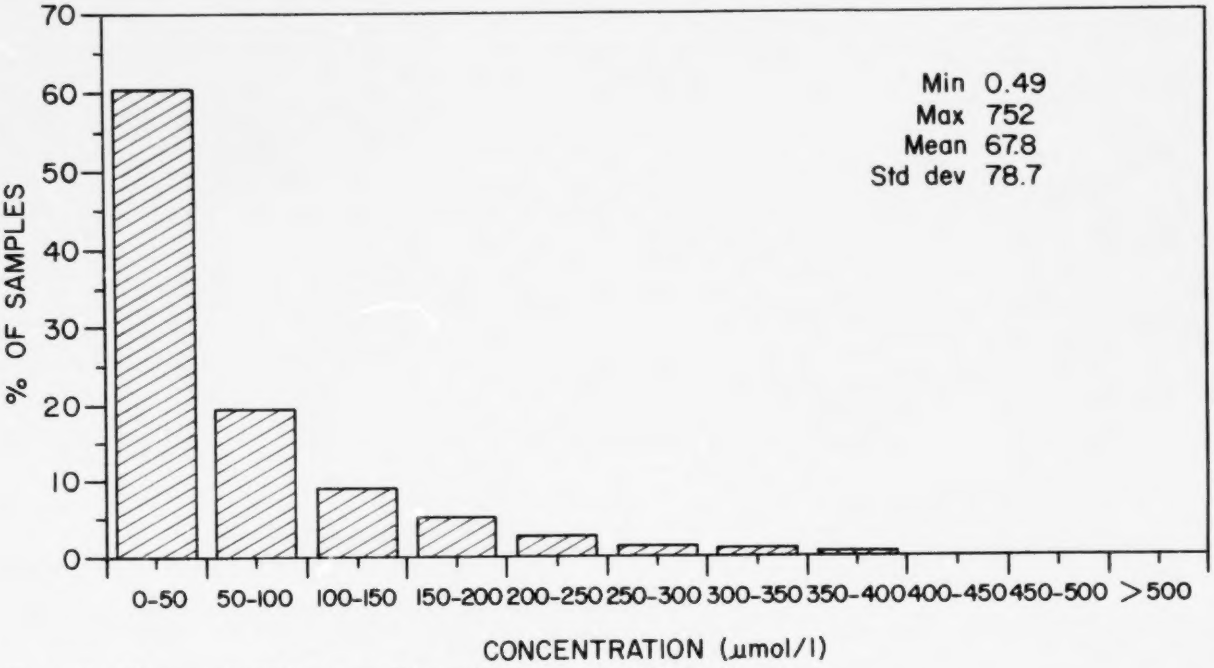

Figure 29.--Nitrate concentrations from 290 cloud water samples (ASRC collector), Whiteface Mountain summit, 1986.

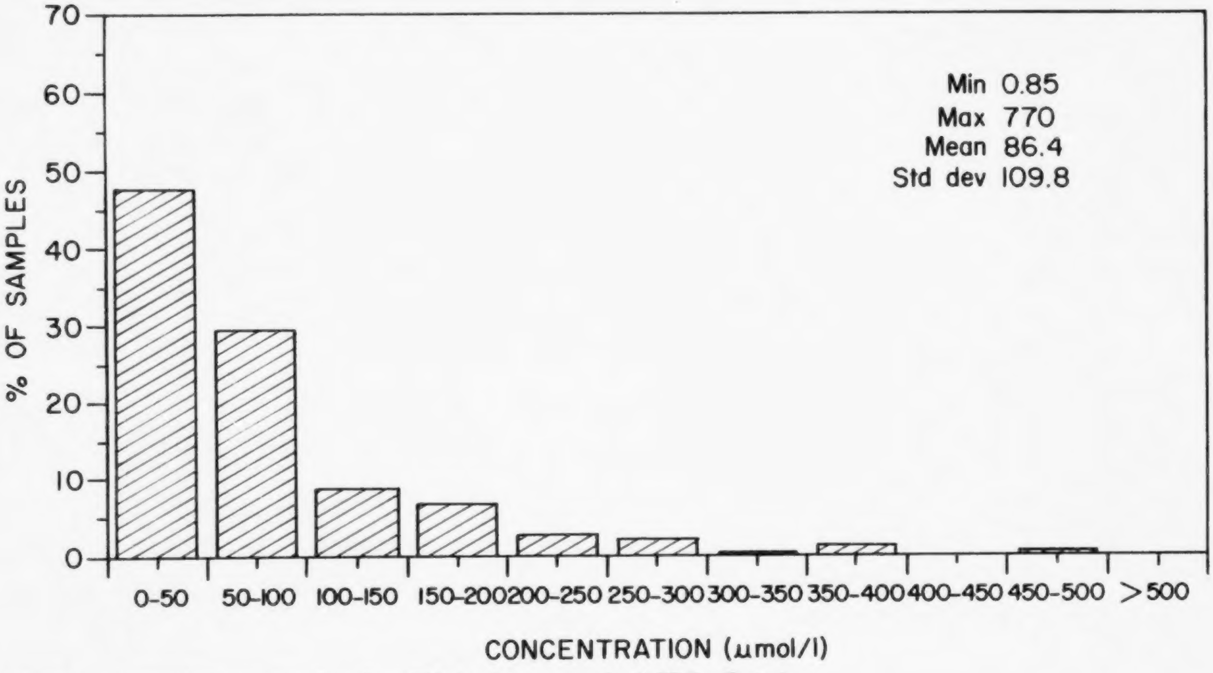

Figure 30.--Ammonium concentrations from 290 cloud water samples (ASRC collector), Whiteface Mountain summit, 1986.

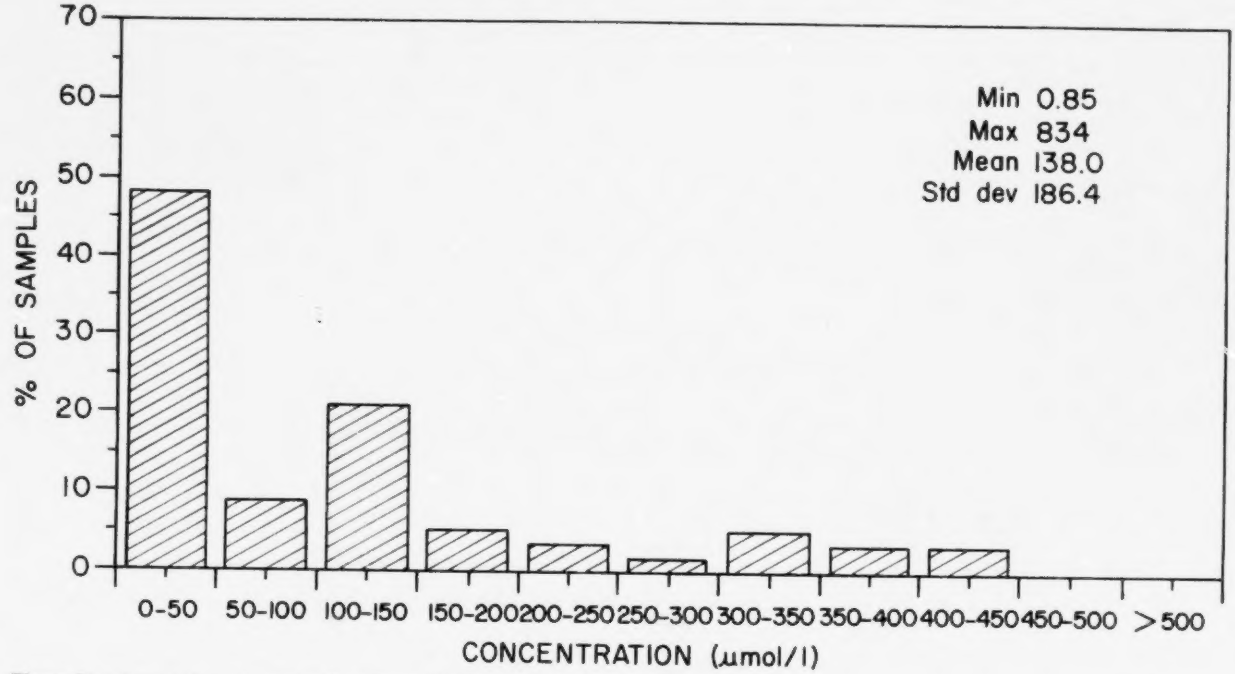

Figure 31.--Ammonium concentrations from 61 cloud water samples (ASRC collector), Whitetop Mountain summit, 1986.

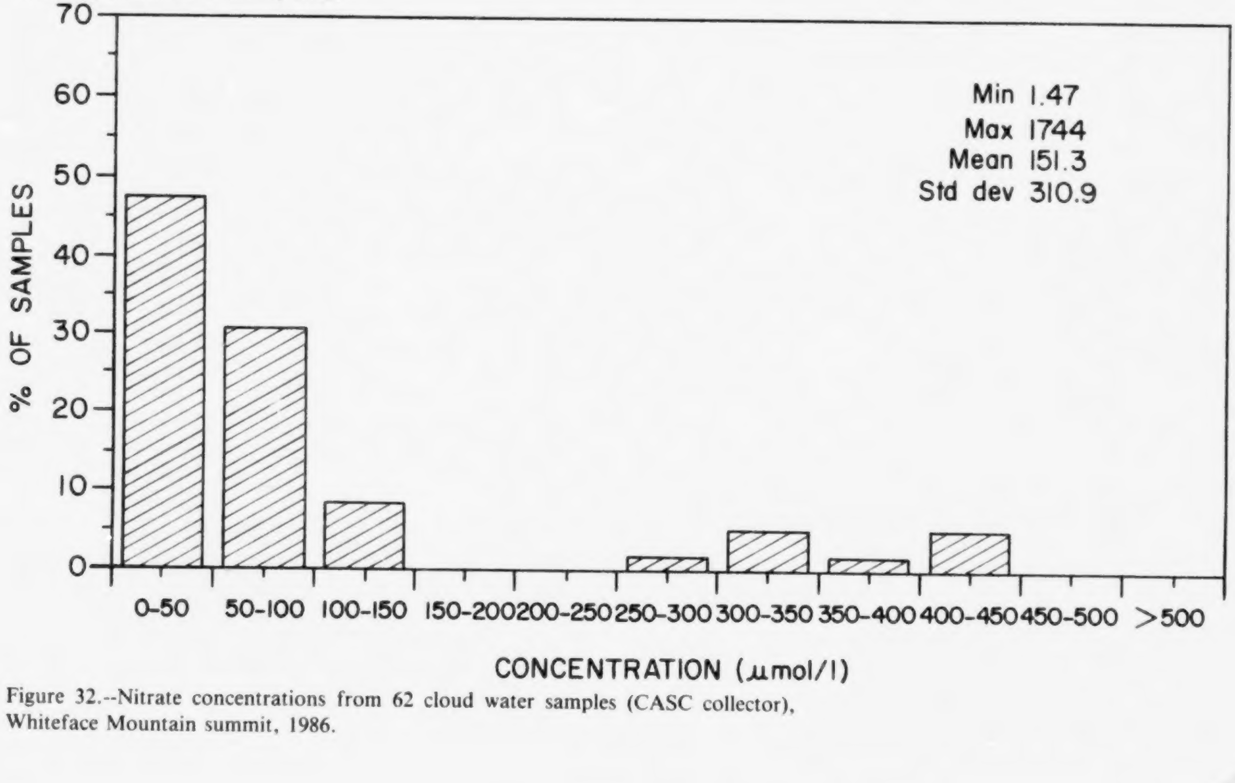

Figure 32.--Nitrate concentrations from 62 cloud water samples (CASC collector), Whiteface Mountain summit, 1986.

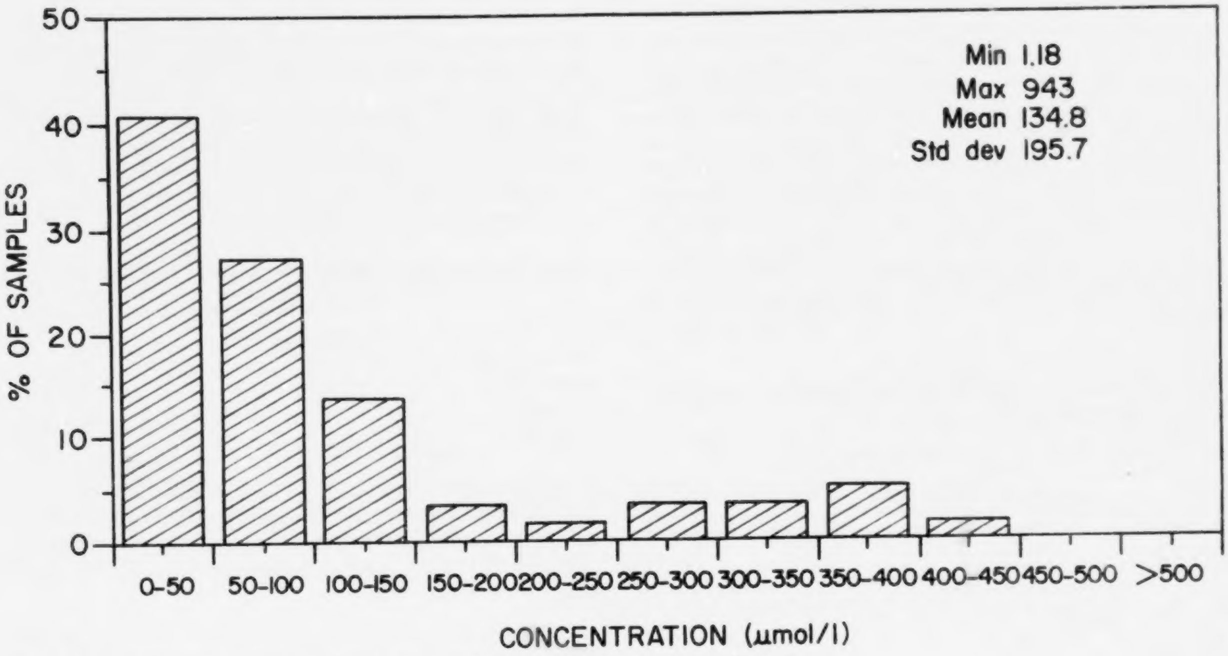

Figure 33.--Sulfate concentrations from 62 cloud water samples (CASC collector), Whiteface Mountain summit, 1986.

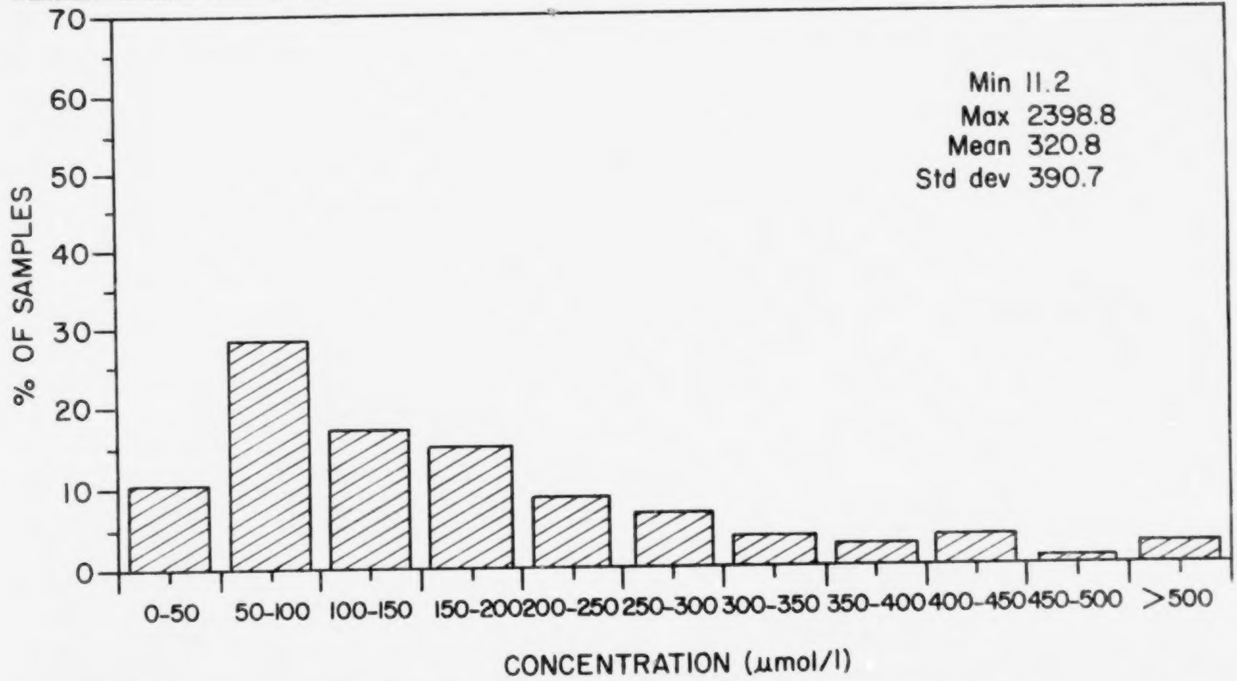

Figure 34.--Hydrogen ion concentrations from 129 cloud water samples (CASC collector), Whiteface Mountain summit, 1986.

Caution should be taken in comparing results between sites. Each site's field season covered a slightly different portion of the year and the same events were not sampled in most cases (see Table 6). The number of samples used to develop each distribution also varies among differences in the events sampled rather than the variation in geography and topography among sites. In 1987, all sites will be in the field for intensive monitoring efforts at the same time. This coordination of collection schedules should make comparison of exposure frequency distributions more meaningful. With the above remarks in mind, a comparison of exposure frequencies at Mt. Mitchell and Whitetop Mountain (which are located less than 100 miles from each other) are presented in Table 6.

Table 6.--Mean ion concentration (μmol/l) of cloud water at Mt. Mitchell and Whitetop Mt., 1986

Site	Hydrogen	Ammonium	Nitrate	Sulfate
Whitetop	321	138	157	135
Mitchell	377	118	96	150

These results in Table 6 indicate some similarity in exposure doses in the region. A true statistical analysis will only be possible when the coordinated effort mentioned previously is complete.

Table 7 shows the mean pH (from hydrogen ion concentrations) of the samples collected at each of the four summit sites. Again, only a qualitative comparison can be made within the limitations of the data set, but the fact that the mean pH of cloud water at all sites was below 3.7 should be noted.

Table 7.--Mean pH of cloud water samples collected in 1986

Site	No. of samples	Mean pH
Mt. Mitchell	231	3.42
Shenandoah	38	3.67
Whiteface	329	3.68
Whitetop	129	3.49

Continued cloud water sampling in 1987 will allow for more reliable temporal and geographic comparisons of ion distributions among sites. This effort will help forest scientists to refine their estimates of total exposure of montane forests to ions in cloud water.

This research has been funded through a cooperative agreement with the U.S. Environmental Protection Agency (813-934010) as part of the Mountain Cloud Chemistry Program.

The Role of Quality Assurance in the Spruce-Fir Forest Research Cooperative

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Abstract

Quality assurance is an integral part of the Forest Response Program providing administrators with data of defined and documented quality for the synthesis and integration of research results. The broad range of research conducted and the large number of projects participating in the Forest Response Program make the close coordination of activities important to ensure that the objectives are accomplished. Some of the quality assurance activities discussed include; the development of research protocols, the establishment of interlaboratory sample exchanges, and the review of project internal quality control procedures. The role of quality assurance in the Spruce - Fir Cooperative is described.

Introduction

The regulatory function of the U.S. Environmental Protection Agency (EPA) necessitates that all environmentally related data from research and monitoring projects it supports be of known and documented quality. Projects funded by the EPA provide information to decisionmakers formulating or changing current environmental policy and legislation (U.S. EPA 1986). Due to this highly visible role the EPA began developing guidelines for data collection in the late 1970's. The guidelines ensure that each facility generating data establishes procedures to document that the precision, accuracy, completeness, comparability, and representativeness of data satisfy the objectives defined by the projects it supports. Unknown data quality, lack of comparability, differing methodologies, and sample degradation due to delays in sample collection and analysis efforts are some of the problems that can be minimized if quality assurance is made an integral part of project and/or program design (U.S. EPA 1987).

The establishment of formalized quality assurance programs is still relatively new to the U.S. EPA. In 1984, the first mandate was issued by the Agency requiring that QA be incorporated into all environmental data collection activities (U.S. EPA 1986). This paper reviews the role of quality assurance in the Forest Response Program (FRP) which is funded in part by the U.S. EPA, in part by the USDA Forest Service, and in part by the foresty industry. It discusses, specifically, the implementation of quality assurance in the Spruce-Fir Research Cooperative (SFRC) and, in general, the coordination of quality assurance (QA) activities in the FRP.

Organization and Objectives

The Quality Assurance Management Staff, of the EPA's Office of Research and Development is responsible for the establishment and oversight of an agencywide QA program. They develop guidance materials and review the activities of QA programs while requiring the individual organizations set up mechanisms for assuring an effective QA process is in place (U.S. EPA 1986). Each EPA program office, laboratory, and regional office has personnel assigned to implement QA for every program and project it supports. The EPA's Environmental Research Laboratory, in Corvallis, Oregon, has oversight for QA in the FRP. They provide guidelines for achieving data quality and regularly evaluate the effectiveness of FRP QA activities (U.S. EPA 1985).

The FRP is organized into four research cooperatives covering the contiguous 48 states. Each cooperative works to evaluate the effect of air pollutants on their respective forest regions. This organization lead to the assignment of one QA Specialist at each cooperative. Figure 1 shows the direct line of QA administration from the EPA offices to the FRP.

Two other groups formed within the FRP support the research cooperatives; their data-gathering activities also require QA. The National Vegetation Survey (NVS), one of these groups, has many projects, each designed to contribute to one of the four cooperatives. These projects, therefore, receive QA review by the respective cooperative QA specialist. The other FRP support group is the Atmospheric Exposure Cooperative (AEC). The AEC, not shown in Figure 1, is funded entirely by the EPA and QA oversight is provided by the EPA's Environmental Monitoring Systems Laboratory in Research Triangle Park, NC.

The goal of QA is to provide data of known and documented quality for the evaluation of air pollutants effects on forest ecosystems. In order to accomplish this special demands for flexibility and innovation are placed on QA in the FRP. The combination of large numbers of projects, the broad scope of the research, and the wide distribution of research locations, which characterize the FRP, is unusual in EPA funded research programs. QA in the FRP, therefore, emphasizes methods testing and the development of research-oriented data quality evaluation. The general objectives to accomplish QA goals for the FRP are stated below:

1. Document data quality through qualitative and quantitative assessments;
2. Ensure comparability of data collection, observational information and/or analytical procedures within and among cooperatives, where appropriate, and
3. Examine, evaluate, and adjust research and QA activities to ensure compliance with standard or approved protocols and procedures (U.S. EPA 1987).

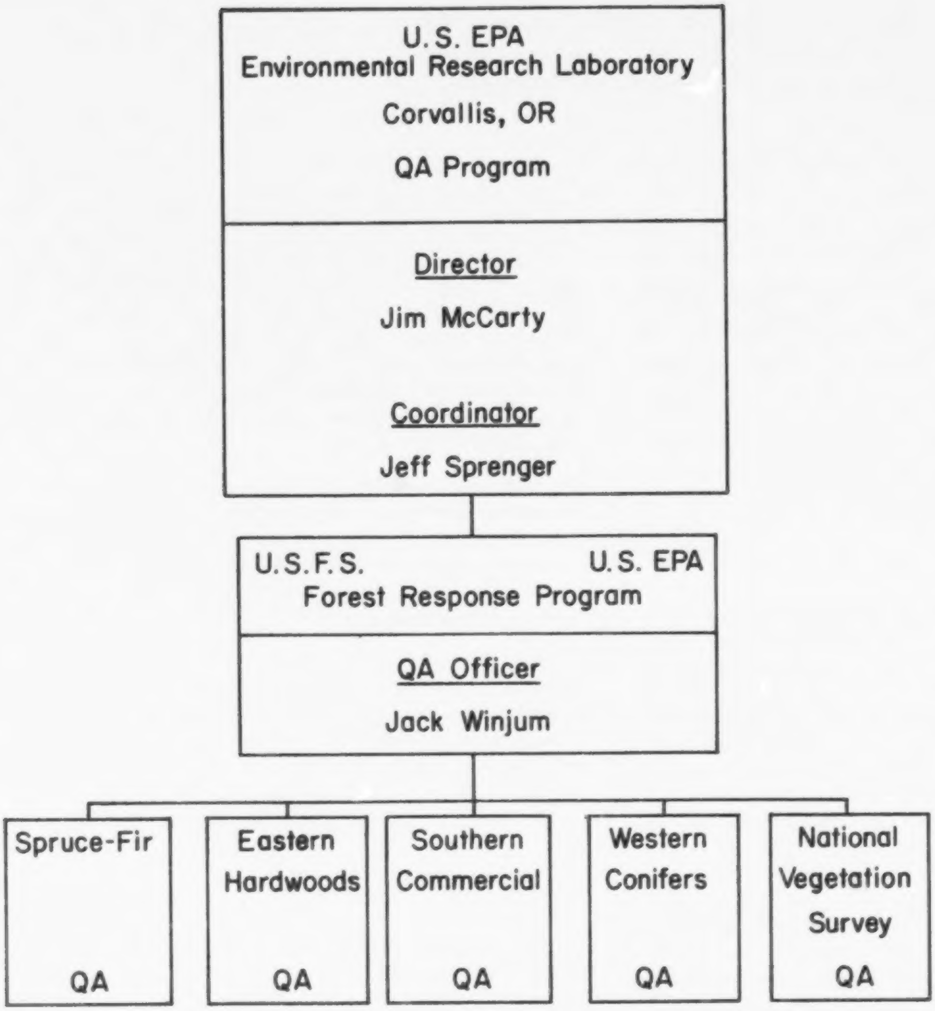
U. S. EPA
Environmental Research Laboratory
Corvallis, OR
QA Program
Director
Jim McCarty
Coordinator
Jeff Sprenger
U. S. F. S.
U. S. EPA
Forest Response Program
QA Officer
Jack Winjum
Spruce-Fir
QA
Eastern Hardwoods
QA
Southern Commercial
QA
Western Conifers
QA
National Vegetation Survey
QA

Figure 1.--The organization of the Forest Response Program quality assurance staff within the Office of Research and Development, U.S. Environmental Protection Agency, Washington, D.C.

Quality Assurance Implementation

Quality assurance is defined as a process for obtaining data of known quality (U.S. EPA 1986). How the process is applied is dependent on the research, testing, or monitoring goals. In the FRP cooperatives the process is implemented at three different levels; project internal, among the projects in a cooperative, and among the cooperatives of the FRP. It is important that the research administrators at each level determine the intensity of data quality control needed to achieve the goals set. If this is not the case then both time and money are wasted by either over or under-evaluating data quality.

Establishing and implementing quality assurance is, therefore, guided by the scientists and administrators, and it is their responsibility to provide data of known quality. QA staff work with the scientists and administrators and are charged with: providing the resources and materials to allow for the definition and documentation of data quality; developing methods to compare differences in equipment, analytical procedures, and measurement methods; and reviewing the processes developed to define data quality and making sure they comply with EPA guidelines.

Project QA

QA implementation in the SFRC begins at the project level. In compliance with the funding agreement, each project submits a detailed description of the methods used to define and document data quality. Successful QA implementation depends primarily on documentation, with the following objectives:

1. To demonstrate that data quality is monitored. For example, good laboratory practices may require that a conductivity meter be calibrated each time it is used. QA dictates that the analyst write down that it was calibrated, record the results, and note any indication that the meter was not functioning properly.
2. To assure accountability of the data, e.g. the data reported do represent analyses on the sample as submitted. Sample tracking is carried out to show that there are safeguards against sample mix-up.
3. To provide traceability of reported data. Each result reported should be easily traceable to the analyst, the method, the sample collected, and the condition of the instrument used.
4. To show that reasonable precautions are taken against data falsification. For example, computer programs used are write protected.

Documentation is essential to QA. It is not adequate to conduct checks on data quality, but the fact that they were conducted must be documented, as well as by whom, when, and with what results. Data integrity is necessary to good science, and many of the requirements of QA in the FRP are regular activities in the participating projects. But the level of documentation required is new. QA requires more work for the same amount of output. But an effective QA program means that the scientist not only knows the quality of the information generated but has the data to prove it. The FRP requires this level of documentation because of the potential use of the FRP assessments to alter existing air pollution regulation.

Due to the emphasis on research, as opposed to monitoring in the SFRC and the FRP, the QA Project Plan normally required at the initiation of projects is not adequate. Instead, the QA Project Plan is submitted as a draft and updated regularly as methods are refined and tested. It is also incorporated into the Work Plan to minimize documentation efforts on the part of the scientist.

The documentation submitted to QA staff at the initiation of a project includes; information on the experimental design and statistical analyses planned; the equipment/instrumentation used including calibration and maintenance activities; personnel and their training; sample collection, preparation, and analysis procedures; data quality objectives; and data mangement, including validation and verification methods. Perhaps the most important component of this documentation are the data quality objectives.

Data quality objectives describe the precision and accuracy of a specific measurement technique, analytical procedure, or observation considering the equipment used. For example, analysis of aluminum content for spruce foliage digestions on the atomic absorbtion spectrophotometer. Because the level of precision and accuracy attainable is not necessarily known at the beginning of a project, this information is provided as estimates. As the project proceeds, control data, in the form of checks on duplicates, spikes, reference samples or remeasurements allows the scientist to refine the estimates into realistic objectives. Data quality objectives are then used throughout the duration of the project to monitor the quality of the information or data generated.

To evaluate whether the documentation is thorough and actually represents project activities audits are conducted. There are several ways they are carried out. Audits are conducted on every aspect of the research from sample collection through analysis and data management. These are called technical systems audits; they provide the quality assurance staff with a good basis from which project compliance may be assessed. Another method is to review, in detail, data quality checks, for example, data from certified and in-house reference standards on analytical equipment, or plot remeasurement data on the field work. These are called performance audits.

Following the increased documentation required, audits are one of the least popular QA activities with the participating scientists. At most facilities (unless one is dealing with a certified laboratory which is audited annually) audits are an entirely new phenomena.

Unpopular though they may be, audits have proven essential to keeping up with changes in both the focus of research, as well as changes in procedures and personnel in the projects.

Cooperative QA

The implementation of quality assurance within the SFRC is carried out following the research priorities for this cooperative. Two basic approaches are used to study the effects of atmospheric pollutants in the SFRC: (1) epidemiological studies are used to identify spatial or temporal patterns in forest condition which may be related to natural or anthropogenic impacts; and (2) physiological/ecological research, which study the effects of environmental conditions on the health of trees or stands. The research includes controlled laboratory, greenhouse, and field studies which expose tree species to various pollutants, alone and in combination. Scientists observe such phenomena as; changes in carbon allocation, metal mobilization and nutrient leaching in soils, foliar leaching, altered incidence of winter injury, changes in regeneration and reproduction, and increased susceptibility to insects and pathogens.

Many of the epidemiological studies in the Cooperative are conducted on the six intensive field study areas located in the Appalachian Mountains. On these sites insect and pathogen surveys, stand inventories, soil and foliar chemical and physical properties, and disturbance histories are evaluated. QA staff work with the scientists to ensure that comparable methods are used. Joint training sessions and workshops are commonly employed.

In the physiological research within the Cooperative project goals differ widely and QA activities are directed at ensuring consistency in the methods used. Methodology testing, equipment testing, and workshops are the major activities of the QA staff. Independent equipment testing has been organized for all gaseous pollutant analyzers under the guidelines described in the EPA's Handbook for Air Pollution Measurement Systems. Analyzers are independently calibrated with equipment certified by the EPA. All analyzers used in the Cooperative are scheduled for calibration at the initiation and shortly prior to conclusion of the exposure regime. This check verifies the calibration and quality control procedures at the research site. If problems are noted corrective measures are recommended.

Methodology testing is established by QA staff through initiatives funded to evaluate how differences in procedures or equipment can affect research addressing the same mechanism or studying the same aspect of epidemiology. This activity is an especially important part of QA in the FRP because of the emphasis on developing or adapting research methods, as compared to the emphasis on established monitoring procedures in other EPA programs. Several initiatives are currently underway including, cold tolerance testing, wet versus dry analysis of soils, automatic injection of aliquots into a gas chromatograph in comparison to manual injection. This area needs to be expanded if QA is to provide information needed for the integration of research results at the conclusion of the Program. A number of other initiatives are currently being considered for funding in 1988.

Communication between the scientists in the SFRC is important if the Cooperative is to achieve its objectives. The QA effort enhances communication by organizing workshops and meetings designed to develop common experimental protocols or adapt instrumentation and methods to test specific hypotheses. For example, QA workshops and meetings have been organized successfully to coordinate projects working independently on one site and those working together on different sites, to develop tests of different procedures used to study the same hypothesis, and to encourage the exchange of material between projects and thereby increase the information gathered from each effort. Joint training sessions have a similar function and have been used effectively with the field crews collecting vegetation and insect and pathogen data on the six intensive research sites in the Cooperative. This training is especially important because some of the information collected in these projects is subjective, i.e. crown vigor, percent needle loss, and the identification of insect or pathogen damage. This activity, in turn, reduces variability in the results by ensuring all personnel are trained in the same manner and provides the basis for quantifying repeated measurement error in and between field crews.

Forest Response Program QA

Coordinating QA activities is the focus of the Program-level implementation. Coordination requires the greatest effort because of the large number of projects and their diverse locations. Some of the QA activities implemented at the Program-level to help coordinate QA include; the development of common research procedures, the establishment of an interlaboratory testing, and the development of a tracking system.

The development of standard operating procedures for laboratory analytical techniques, field measurements, exposure systems, physiological measurements, and data management have been compiled through workshops with the participating scientists, into a series of Methods Manuals. The standard operating procedures are common research methods formed through a consensus among FRP scientists on the recommended technique for measuring, analyzing, or observing a specified variable. The purpose of these manuals is to:

1. Provide common research methods to aid the synthesis and integration of results for assessment purposes;
2. Provide standardized QA techniques within the research protocols to allow for the evaluation of data quality; and
3. Prevent duplication of documentation efforts among investigators using these protocols.

The Methods Manuals have been especially useful in coordinating activities at the six intensive research sites and in the exposure research studies in the SFRC. However, the development and use of standard operating procedures does not have as large a role in the FRP it has in other programs because of the emphasis on experimentation and methods development in this Program.

Interlaboratory testing is another aspect of QA organized at the Program-level. The goals of interlaboratory testing are; to provide a measure of the precision and accuracy of analytical methods run routinely by different laboratories, to estimate the precision and accuracy between laboratories, and to identify weak methodology or training problems. Standard samples have been developed for foliage and soils, and are being developed for rainwater, soil solutions, and stem tissue. Samples from the homogenized standard are distributed to the scientists and the results from their analytical procedures are sent back to the QA staff for evaluation.

A tracking system for all projects in the FRP is currently being developed (Steve Byrne, pers. comm.). The tracking system will contain detailed information on all projects, e.g.: type of study, variables measured or observed, equipment and instrumentation used, and number of samples or observations. This system will provide QA staff and other FRP participants with a convenient way to access needed project information. For example, QA staff will use the tracking system primarily to determine whom to distribute standard samples for interlaboratory analysis or the number of projects using the same type of equipment so that comparability studies can be carried out.

Conclusions

Effective control of data quality within the projects, and consistency of data quality among the projects, is important to the success of QA implementation. The ongoing establishment of interlaboratory testing, equipment testing, comparability studies, and other QA activities, further enhance FRP QA. Its implementation in forestry research, however, is relatively new and time is needed to develop a strong QA component in the FRP. QA was established well after the FRP began, limiting its scope. Ideally, QA should be a part of the initial planning stages of a program and direct the type of information provided in the objectives which guide the administrators.

Every quality assurance program must have a set of objectives which are clearly stated and supported by both management and staff (Garfield 1984). The objectives of the Forest Response Program provide general statements of the overall goals. These, in turn, are interpreted in the Cooperative plans into a sequence of tasks which must be accomplished to meet the goals for the ecosystem of study. The tasks are scientific approaches, which do not include statements on the quality of data needed by policymakers for creating new or altering existing legislation. The lack of detailed qualitative, not to mention quantitative, statements of data quality has hindered the establishment of QA within this Program. It focuses QA activities on the projects instead of the program goals, when it is the Program goals which should determine the intensity of QA implementation in the projects.

Both the late initiation of QA in the FRP and the lack of more specific data quality objectives have caused problems for the QA staff. But the strong support give the QA staff by the cooperative administrators and the participating scientists have helped the QA staff to minimize these problems. QA is involved in developing and adapting methods as much as the projects are in the FRP. Its implementaiton is becoming more effective with time. The successful application of QA concepts, which are widely used in industry, in analytical laboratories and in monitoring programs will determine the role it will have in future programs.

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Seed and Seedlings for the Spruce-Fir Research Cooperative

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Introduction

We provide seed or seedlings of known geographic origin to investigators in the size, quantity, time, pot, and/or physiological condition necessary to optimize experiments. Except for unusual circumstances, all seed and seedlings are handled under uniform environmental protocols.

When investigators request specific seed or plant material, the project staff makes every attempt to collect, purchase, or acquire seed of the three research species (red spruce, balsam fir, or fraser fir) to fill requests. The goal of the project is to have available 10 individual tree seed collections from each of 20 sites throughout the natural range of each species. In addition, six specific sites are being sampled: the so called "intensive" study areas of Mt. Mitchell, North Carolina; Mt. Rogers, Virginia; Clingmans Dome, Tennessee/North Carolina; Mt. Moosilauke, New Hampshire; Whiteface Mt., New York; and the commercial forests near Howland, Maine. Collections from the intensive sites are more than 50 percent completed and the rangewide species collections are approximately 30 percent completed. We are still waiting for a bumper cone crop rangewide for each species to fill out the collections.

Individual tree collections and provenance collections since 1985 are extracted, tested, and stored by Dr. Frank Bonner, USDA Forest Service, Starkville, Mississippi. Pre-1985 collections were extracted by the supplier and are stored at the Forestry Sciences Laboratory, Durham, New Hampshire, until requested or needed.

Quality Control

Seed Quantity and Quality

Evidence is accumulating for red spruce that fewer viable seeds per cone are produced the higher in elevation of source collection. Hoover (1904) found viability at approximately 5 percent for high-elevation black spruce in New Hampshire. Bonner (personal communication) has found from our collection that the percentage of viable red spruce seeds from high elevation ranges from 2 to 5 percent. Bonner's data are from cones collected from poor cone crop years and poor viability may be due in part to a high percentage of self seeds or to poor pollination. We need to gather information from a bumper cone crop before a general statement of low seed set and viability from high-elevation red spruce can be made. In any event, the consequences to the program are that we pay a quantity and quality price in red spruce seed as we collect at higher elevations. Depending on future research needs for quality and quantity seed, we may have to use lower elevation collections to meet these requirements.

Growing Media

To ensure that all investigators receive seedlings that are as similar as possible, we grow the seedlings in standard media. The following mix works well:

Quantity	Description
1 bag	6 cubic feet "Mr. Pete" peat moss
2 bags	22-pound bags of "Terra Lite" vermiculite (W.R. Grace)
1512 grams	High Mg Lime (Agway)
2268 grams	Osmocote 18-6-12 (8-9 month)
453.6 grams	Aqua-Gro "G" Granular
38 grams	Micronutrients (Peters)
269 grams	0:45:0 fertilizer (Agway)

The ingredients are mixed for 10 minutes in a 1-cubic-yard soil mixer prior to use.

Containers for Seeding

All seedings are grown the first year in either 1½-by 1½-by 8-inch paper tubes or 1½-by 8-inch "Ray Leach conetainer" plastic tubes. The paper tubes have a larger media capacity and allow for larger 1-0 seedling growth.

Seeds sown in the fall (November) are grown in paper tubes. Seeds sown in the winter (February) are usually grown in "conetainers." These "conetainers" are for back-up, for late requests, and for transplanting in the State of New Hampshire Nursery. There is a trade off between the containers. The paper tubes allow larger seedlings and better moisture retention but are subject to more fungus problems. The "conetainer" seedlings are easier to transplant and have fewer disease problems, but they are smaller and tend to have end-of-season moisture retention problems.

Containers for Transplanting

We will transplant seedlings into any type container that investgators need for their research. However, for comparison purposes we have chosen two pots as standards; the 4 by 4 by 14-inch citro pots and the 6 by 6 by 16-inch citro pots. These pots are very economical on space yet have enough media volume for good seedling development. Because the containers are high, they require side support or need to be partially buried.

Environmental Conditions

Seedlings are grown in their respective containers on greenhouse benches under constant 70° F, 12-hour (5 p.m. to 5 a.m.) supplemental lighting, and automatic watering. The water protocol is as follows: 16 minutes of water between 10:00 a.m. and 12 noon (system is shut off on overcast days and dry spots are watered by hand as needed).

After 16 weeks, seedlings are fertilized once a month through early July with 15:15:15 fertilizer at 24 ounce dry weight per 4 gallons of water and applied with a Hozon at the rate of 1:15.

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Seedlings receive fungicide on a weekly rotation of THIRAM (2½ tablespoons per gallon), BENLATE (½ tablespoon per gallon) and CAPTAN (2½ tablespoons per gallon) and are treated with insecticide (MALATHION) if needed.

Shade

All first-year and potted seedlings are moved to lath houses by June 1. The trees receive approximately 50 percent sunlight, fungicides and insecticides, and water as needed. The seedlings receive no supplemental fertilization, i.e., only the residual from the soil mix. This prepares the seedlings to be less succulent as they enter the fall dormant season.

Maintenance and Repair of Equipment

The greenhouse and headhouse are protected by a 24-hour alarm and call system to ensure that the facilities will have minimum "down time". The system monitors high and low temperatures in each of the two glass houses, and checks for furnace failure, electrical failure, and fire. Electrical service is assured to the complex with an automatically controlled propane fueled 60-kw electrical generator. Also, spare furnace parts are on hand to ensure minimum furnace down time. Items on hand include two complete circulator pumps and motors, fuel pump, relief valves, electric motors, and electrical items. We do not stock major plumbing parts, such as pipe, fittings, or fin tubes. We do stock extra greenhouse glass, timers, watering controls, and lighting elements and bulbs.

Lessons and Information Learned

Growth of Red Spruce

We have been growing red spruce from seed collected in Nova Scotia, Maine, and New Hampshire in 1½ by 1½ by 8-inch paper tubes. Our 1986 seedlings averaged 25 cm by mid September with no visual symptoms of stress caused by container size. There were significant differences among sources for total height indicating there are juvenile genetic differences among sources. Also, there were differences in height of seedlings within sources indicating there are genetic differences within sources. Red spruce seems to have ample genetic differences within and among sources to possibly accommodate environmental and anthropogenic stress.

Red spruce seedlings seem to be quite resistant to environmental stresses when they are supplied with adequate fertilization and moisture. Before we could move the 1986 seedlings from the greenhouse to a shade house, the temperature reached over 95°F for three days in a row. The high temperatures plus movement to a shade house did not initiate bud set. The seedlings continued to grow until late September with no supplemental fertilization.

Seedlings stored outside in pots or trays need to be protected from winter desiccation and small mammals. Bailed hay stacked around the storage area protects the seedlings from wind and acts as a trap for blowing snow. The trapped snow acts as additional insulation. Approved rodent baits (HAVOC) need to be applied and monitored throughout the winter to ensure that the storage area is free of feeding and nesting rodents.

Growth of Firs

Our limited experience with container-grown firs has taught us that Fraser fir is easier to grow than balsam fir because it seems to be more tolerant to variations in moisture and temperature though we have no hard quantitative data to back-up our observations. During the second season of production, we were able to grow larger and more uniform seedlings from the same seed source with less fungus problems by reducing the duration of watering to the present red spruce water protocol.

Rooting of Red Spruce Cuttings

In 1986, we tried to root 2- to 4-inch cuttings from the middle of the crown of 10 31-year-old red spruce in the following three media; (1) 100 percent perlite, (2) 75 percent perlite-25 percent ground sphagnum, and (3) 50 percent perlite-50 percent ground sphagnum. All media were crossed with three treatments, dip in Hormodin 3, dip in 25,000 ppm NPIBA (2½ percent), or no treatment (control). The cuttings had under-bed heat, mist for 5 seconds every 5 minutes, and continuous lighting. We graded the cuttings by diameter, the largest in block I to the smallest in block IV. Results ranged from no root callus for some trees to 40 percent root formation for one tree in block I with no treatment and in the 3:1 perlite-ground sphagnum media. The same tree rooted 30 percent in the same block with no treatment and in the 1:1 perlite-ground sphagnum media. We feel we can improve our rooting percentage by selecting larger diameter cuttings with larger buds and needles. However, we also feel we will probably get very little rooting with cuttings from some physiologically mature trees. Rooting of plant material from high-elevation trees seems to be an alternative to waiting for a high-quality and high-quantity seed crop. Hopefully, cutting from mature trees will root well enough to make studies practical.

Conclusions

1. The project has developed protocols to produce quality spruce-fir seedlings for investigators.
2. The project is obtaining seed of known origin for use in spruce-fir research studies.
3. Cuttings from some mature red spruce trees will root in a ground sphagnum/perlite rooting medium.
4. Rooting of cuttings of high-elevation red spruce may be the alternative to poor quality and quantity seed crops at these elevations.
5. Facilities and equipment need a quality monitoring program with proper replacement parts and back-up systems to ensure quality seedling production.

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Modeling Activities Within the Spruce-Fir Research Cooperative

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Abstract

The Spruce-Fir Research Cooperative is actively involved in a diversity of modeling approaches to address the effects of atmospheric deposition on the spruce-fir forests of the Eastern United States. Initially, a conceptual model was developed to assist in the research planning stages of the cooperative. Subsequently, efforts have been focused on stand level modeling with FIBER, a highly empirical model, and FORET, a more mechanistically based, ecological model. These will be used for analysis of temporal/spatial variability and alternative pollution scenarios. Recently, an individual tree, process based modeling approach has been initiated that will be instrumental in synthesizing and integrating the dose-response, mechanistic research that is being conducted by the principal investigators.

Introduction

Recently, considerable attention has been focused on the decline of the red spruce--fir forest types in the Eastern United States. In the high-elevation forests of the Northeast, for instance, declines have been documented by Scott et al. (1984) on Whiteface Mountain, New York, and Vogelmann et al. (1985) on Camels Hump, Vermont. Similarly, declines have been reported in the spruce-fir forests of the Southeast by Bruck (1984) on Mt. Mitchell, North Carolina, and Adams et al. (1985) in the mid-Appalachian forests. Although considerable mechanistic research is being conducted to determine the causal factors, both natural and anthropogenic, the role that atmospheric deposition plays is unanswered. Thus, the Spruce-Fir Research Cooperative (SFRC) has been developed under the Forest Response Program (FRP) of the National Acid Precipitation Assessment Program (NAPAP) to provide information on the response of red spruce--fir forests to atmospheric deposition. The SFRC has been addressing the following three broad policy questions.

1. Is there a significant problem of forest damage in North America that might be caused by acidic deposition, alone or in combination with other pollutants?
2. If so, what is the causal relationship between acid deposition alone or in combination with other pollutants and forest damage in North America?
3. If there is a causal relationship, what is the dose-response relationship between acidic deposition, alone or in combination with other pollutants and forest damage in North America?

Within the SFRC, modeling will be used in a variety of ways to help address these issues.

Objectives

The modeling effort within the SFRC will be focused on the following objectives:

Objective 1 - To synthesize and integrate the current state of knowledge of red spruce--fir forests in the Eastern United States and, thus, aid communication among interdisciplinary scientists and interagency policy makers.

Objective 2 - To formulate a model that can be used as a research planning tool in developing and testing new hypotheses for study by cooperative scientists and in redefining research direction for cooperative management.

Objective 3 - To estimate the dose-response effects of atmospheric pollutants on red spruce--fir trees and stands.

Objective 4 - To develop a regional red spruce--fir model for the Eastern United States.

Objective 5 - Perform and interpret pollution scenario analysis for decisionmakers in an attempt to evaluate alternative strategies for controlling atmospheric deposition.

The SFRC will be solely responsible for Objectives 1, 2, and 3, while it will cooperate with the Synthesis and Integration Project (EPA - Corvallis, Oregon) on Objectives 4 and 5.

Modeling Characteristics

In the development of a multi-objective, complex modeling effort, it is desirable to specify various characteristics that the modeling approach should adhere to in order to formulate a useful, flexible system capable of responding to future demands and alterations. Several of these characteristics that will be used in our models are described below.

1. The design, development, and implementation of the models should be conducted by a multi-discipline team consisting of modelers, scientists, and decisionmakers.
2. The models should represent a synthesis and integration of the current state of scientific knowledge.
3. The modeling architecture should be of a modular design so that future alterations could be easily accomplished when new research results become available. To further facilitate modification, a structured programming style should be used throughout the computer simulators.
4. In order to increase interaction among other interested agencies and organizations, the simulators should be written in a standard, portable computer language using as few systems dependencies as possible.
5. An attempt should be made to use the simplest modeling formulations possible that will produce the desired output. This will increase understanding and produce additional interaction leading to future modifications.
6. The models should be implemented in an interactive manner and possess user-friendly properties. Graphic capabilities should lead to a "dynamic" modeling approach represented by temporal "snapshots" of the red spruce--fir forests under various atmospheric deposition scenarios.

7. The models should strive to be explicit in treating the uncertainty incorporated in the system.
8. To facilitate model use, future development, and modification, well-documented model descriptions and user guides should be formulated.

Strategy

The development of a model to satisfy the stated objectives is extremely difficult to achieve since the basic phenomenon of tree growth and stand dynamics is poorly understood in natural red spruce--fir ecosystems as is the impact and pathways for physiological mechanisms of pollution damage. Thus, the SFRC has developed a modeling research strategy that will encourage a maximum of scientific creativity within the confines of specific objectives and allow for interaction among scientists within the cooperative, between other FRP components and other national and international organizations. The structural framework for the modeling approach is illustrated in Figure 1.

A.E.A. Model

The SFRC initiated efforts to formulate its research strategy by contracting with Adaptive Environmental Assessments, Inc. (A.E.A.), a Toronto, Canada, based consulting service, to develop a set of rational, defensible research recommendations based on the combined expertise and perspectives of research scientists, managers, and policy makers concerned with the red spruce--fir forest resource.

The specific objectives of the project were to:

1. develop a rational, defensible research program for assessing and understanding the effects of atmospheric deposition on the spruce-fir forests of the Eastern United States.
2. develop a common understanding of the state of knowledge of spruce-fir decline and the possible role of atmospheric deposition, and
3. develop a prototype model of atmospheric deposition effects on spruce-fir forests.

The project objectives were met through a series of scoping, workshop, and technical meetings from September 1985 to January 1986 including 38 participants.

A conceptual model was developed that consisted of a set of natural and anthropogenic stresses that influence the physiological processes and, in turn, are manifested in changes in tree growth, yield, mortality, and decline symptoms (McNamee et al. 1986). The model was further defined by specifying the valued ecosystem components that are ultimately influenced by the stresses. These consisted of (1) growth and yield variables (stem density, basal area, volume), which are appropriate for commercial stands, and (2) esthetic attributes (leaf area index, foliage color, species composition, percent dead biomass, genetic variation), which are of more interest in the recreational, high-elevation forests.

The conceptual model was also used as the framework for developing a distant-independent computer simulation model of a red spruce--fir stand that operates on an annual time step for outputs and a weekly time step for calculating stresses on physiological processes. Workshop participants developed functional relationships for the model processes based on published and unpublished research and professional judgment. Instead of developing a stand model upon which to base the stress components, we used the existing FIBER model (Solomon et al. 1986) to simulate red spruce--fir stand development. This is an empirically based model that uses a two-stage matrix projection technique to simulate growth, mortality, and regeneration.

The major function(s) of the conceptual and simulation models are to synthesize knowledge and aid communications (Objective 1) and for use as a research planning tool (Objective 2). Since current understanding of the effects of the stresses on the dynamics of spruce-fir forests is poor and the required data is too intensive for parameterization, the predictions from the simulator cannot be viewed with confidence. However, it does serve as a prototype model that has been useful within the cooperative.[1]

FIBER Model

Background. FIBER is a two-stage matrix model used for predict growth and yield of even-aged and multi-aged spruce-fir, mixedwood, and northern hardwood stands in the northeastern United States. (Solomon et al. 1986, 1987). One stage of the model consists of regression equations relating transition probabilities for 0-, 1-, and 2-inch diameter growth in 5 years to stand basal area, tree diameter, and proportion of hardwoods. In the other stage, these probabilities are used in projection matrices that predict the stand diameter distribution over time. In addition, equations were developed to predict ingrowth of each species into the smallest allowable diameter class (5 inches) as a function of stand basal area, proportion of hardwoods, and proportion of that species in the stand. The model was calibrated from three data sets that consisted of 359 permanent plots in a softwood forest (Penobscot Experimental Forest, Bradley, ME), 48 plots in an uneven-aged northern hardwood forest (Bartlett Experimental Forest, Barlett, NH) and over 2,500 growth plots from independent sources in northern Maine, New Hampshire, northern New York, and Vermont.

FIBER allows the user to simulate the effects of several management practices and silvicultural treatments over a range of stand densities, harvest intervals, species compositions, and sites. Stands can be managed either by stating the allowable stocking level (basal area, cubic volume) or the time interval to thinning. Thinning can be achieved by specifying the stocking level desired or by using B lines in stocking charts. Thinning options include thinning from above, thinning from below, thinning along a q-line, removal of trees from any diameter class, or thinning uniformly across all diameter classes.

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[1] For more information on the A.E.A. model, see McNamee, Peter; Jones, Michael L.; Greig, Lorne A.; Webb, Timothy M., "Research Planning for the Spruce-Fir Research Cooperative" in the proceedings of this symposium.

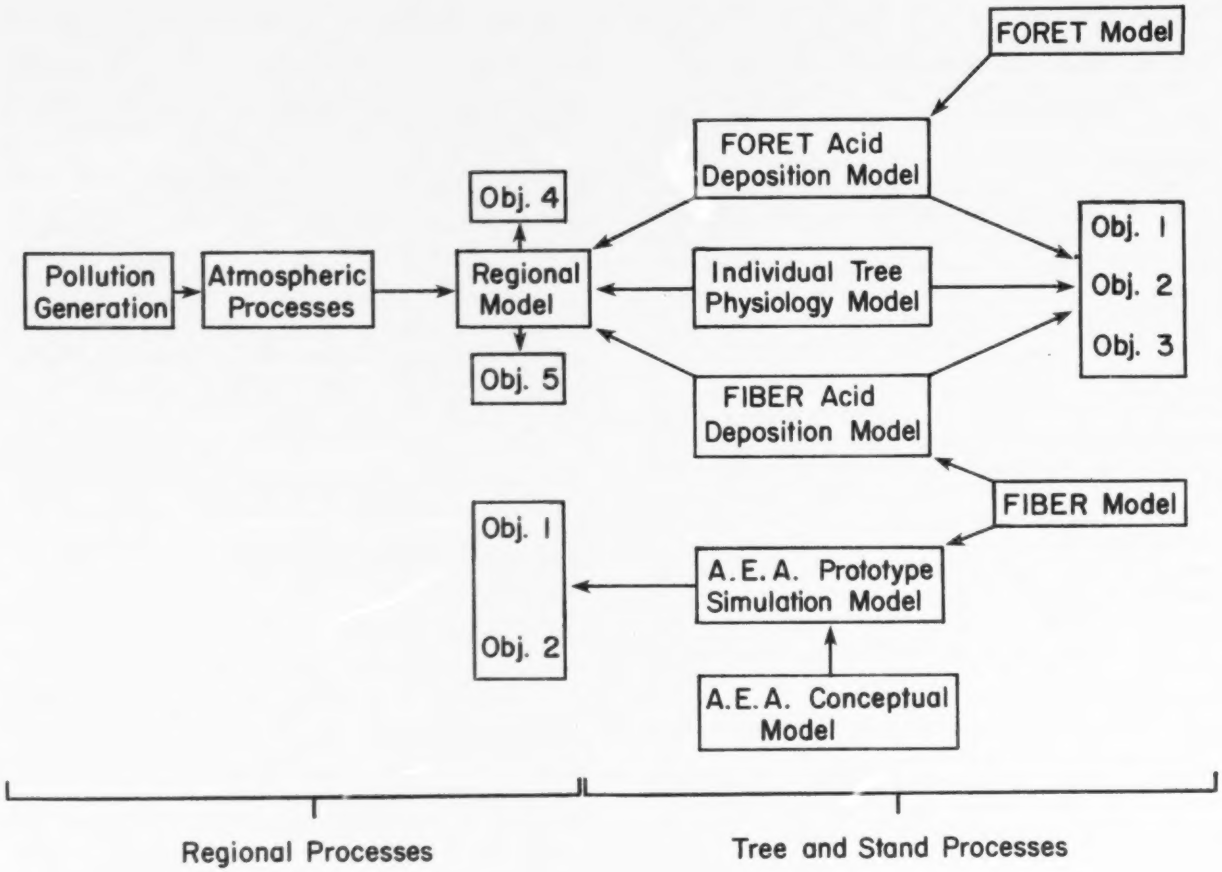
FORET Model
FORET Acid Deposition Model
Obj. 4
Pollution Generation
Atmospheric Processes
Regional Model
Individual Tree Physiology Model
Obj. 1
Obj. 2
Obj. 3
Obj. 5
FIBER Acid Deposition Model
FIBER Model
Obj. 1
Obj. 2
A.E.A. Prototype Simulation Model
A.E.A. Conceptual Model
Regional Processes
Tree and Stand Processes

Figure 1.--Structural framework for the modeling approach in the Spruce-Fir Research Cooperative.

Proposed Work. FIBER will be used by Dr. Dale Solomon, USDA Forest Service, Orono, Maine, to address several issues in the SFRC. Activity is initially focused on analyzing the temporal and spatial variability of growth and mortality within the spruce-fir forest through application and modification of the FIBER model. Currently, FIBER predicts stand dynamics subject to ambient conditions upon which the model was parameterized that included low pollution levels (pre 1965 data) and high pollution levels (post 1965 data). Hence, the data set will be partitioned into low and high pollution segments and then the model will be reparameterized. Optimistically, this will lead to estimation of changes in forest condition and lead to the separation of natural and anthropogenic stresses on spruce-fir forests.

In addition, FIBER will be fitted to the spruce-fir plot data that is being collected at the six SFRC intensive sites. This will further test the reliability of this modeling approach over a larger geographical area and shed insight into how the northern and southern red spruce--fir growth components may differ. Moreover, since this data will consist of soil, insect, and pathogen information as well as detailed vegetation measurements, the regression equations can be modified to incorporate these effects.

It is desirable in any prediction system to estimate the degree of reliability in the estimates by means of confidence intervals. Merely stating a point estimate will not suffice. Recently, considerable attention has been focussed on error propagation and variance estimation in growth and yield models (Gertner and Dzialowy 1984, Reynolds 1984, Mowrer and Frayer 1986, Gertner 1987, Gregoire 1987). Hence, effort will be given to determining a feasible technique for confidence interval estimation in a matrix projection model.

Additional effort will be given to evaluating the influence of stress on the temporal and spatial variability of tree growth and mortality within FIBER using changes in foliar conditions. This is of vital concern to the SFRC since the foliage is the initial point of contact between the pollutant and the tree. Previously, Hayslett and Solomon (1983) developed a matrix model to predict the annual foliage growth of balsam fir. This structure will be further developed and applied to red spruce in expressing the relationships between the influence of external stress and foliage production. The model predicts foliage biomass by age class of needles as a function of (1) foliage biomass production in each age class, (2) the photosynthetic efficiency of the foliage age class, and (3) the proportion of foliage that is retained in each age class. The SFRC is supporting research on three hypothesized mechanisms that may potentially be affected by atmospheric deposition and are directly responsible for foliage biomass. These are foliar nutrient leaching, alterations in carbon production and allocation, and winter injury. Dose response functions could be developed to relate foliage biomass production, photosynthetic efficiency, and foliage retention to various levels of atmospheric deposition. Analytical procedures, such as the Weibull modeling techniques used in the National Crop Loss Assessment Network (Rawlings and Cure 1985), will be investigated for applicability.

FORET Model

Background. FORET (Shugart and West 1979) is a simulation model originally developed for predicting forest dynamics in mixed-aged, mixed-species stands in east Tennessee. It is based on a modification of the JABOWA model (Botkin et al. 1972), which was originally conceived and parameterized using the Hubbard Brook Ecosystem Study database.

The FORET model is an example of a spatial gap model (Shugart 1984) that simulates annual forest dynamics on a small plot (1/12 hectare) by calculating tree growth, sapling ingrowth (from seeds and sprouts), and mortality based on stochastic processes. The model attempts to represent dynamic phenomena by parameterizing general equations based on physiology, morphology, and forestry principles. Unlike empirically based models, FORET does not require large data sets for parameterization and, thus, data could be reserved for independent validations of the model. Currently, the FORET model has been parameterized, modified, and studied for pollution effects (West et al. 1980), nutrient retention properties (Weinstein et al. 1982), landscape dynamics (Weinstein and Shugart 1983) and spruce-fir stand dynamics (Busing 1985).

Proposed Work. Initial efforts are being focused by Dr. Lynn Maguire, Duke University, on parameterizing FORET to the three southern intensive sites currently being surveyed. If promising results are obtained, the model will be fitted to the northern intensive sites which will allow comparisons between northern and southern red spruce--fir forests. In addition, a comparison will be performed between the FORET and FIBER models to assess the strengths and weaknesses of both modeling approaches. It is anticipated that FIBER will be of greater value in predicting while FORET will be more applicable for research planning/hypothesis testing purposes.

The effects of air pollution on red spruce--fir forest dynamics will be incorporated by modification of the growth and mortality functions to reflect physiological processes. Interaction with SFRC principal investigators will yield knowledge of the required physiological processes.

Individual Tree Model

An individual tree, process model will be developed for red spruce based on the theoretical modeling efforts of Dr. David Ford, University of Washington. The process model will have parameters that are biologically meaningful, and, hence, will be useful in addressing policy questions 2 and 3 pertaining to causal factors and dose-response estimation. The three major components of the model--carbon allocation, water balance, and nutrient uptake--will consist of a system of differential equations whose parameters will be estimated from the data generated by the mechanistic studies conducted by the SFRC principal investigators.

Other Modeling Efforts

Several modeling efforts that are not sponsored by the SFRC are of interest and may lead to valuable results that could be utilized in the cooperative's models. For instance, an individual tree physiological model is being developed by Dr. David Weinstein, Cornell University, under the project "Response of Plants to Integrated Stress" funded by the Electric Power Research Institute. The objective is to explain the relationship between plant, soil and litter and the effects of ozone and simulated acid rain. The model will be based on the experimental results obtained in an open-top chamber study focusing on the effects of ozone and acid rain on sapling trees (1 to 1.5 m tall). It will yield a simulation model for predicting photosynthesis, carbon allocation, soil and plant moisture stress, nutrient cycling, canopy leaching and soil solution chemistry subjected to ozone and acid rain. The components of the model will emphasize theoretical aspects and will not be primarily regression functions.

Recently, the International Institute for Applied Systems Analysis

(IIASA) in Laxenburg, Austria, has made considerable research contributions to the problem of acid deposition in forest resources. The RAINS (Regional Acidification Information and Simulation) model developed by IIASA provides the decision maker with a tool for evaluating alternative energey scenarios in Europe (Hordijk 1985) by using an optimization algorithm. The four submodels currently available deal with sulphur emissions, sulfur transport, forest soil acidification, and lake acidity (Alcamo et al. 1985). In addition, a dynamic tree growth model has been developed (Makela 1985) based on the assumptions of the pipe-model theory (Shinozaki et al. 1964a, b), which partitions growth between foliage and wood. In an independent effort, Valentine (1985), also developed a tree growth model based on the pipe-model theory and has extended it to a stand level model (Valentine 1986). Hence, close scrutiny of the IIASA effort and the pipe-theory models will be followed and possibly used in future efforts within the SFRC.

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Modeling Stand Dynamics of Spruce-Fir Forests in the Northeast

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Abstract

Spatial and temporal variability of diameter growth will be calculated across the spruce-fir geographical range and compared to the spatial pattern of atmospheric deposition. This research addresses two scientific questions in the Spruce-Fir Research Cooperative (SFRC): (1.1): Are changes in growth and mortality and the presence of unusual foliar symptomology in red spruce-fir forests greater than those that can be attributed to typical trends and levels of natural variability? (1.2): What spatial patterns, if any, exist in growth and mortality and in the presence of unusual symptomology in red spruce-fir forests, and how do these patterns relate to spatial patterns of pollutant exposure? The forest growth model FIBER will be modified to incorporate elevational effects into diameter growth equations for different time periods for red spruce over the last three decades. The model has been adapted to account for stresses from environmental influences by incorporating additional variables. These variables include changes in the amount of foliage weight as altered by stress.

Considerable attention has been focused on the growth decline within the red spruce-fir forest types in the Eastern United States. In the high-elevation forests of the Northeast, declines have been documented by Vogelmann et al. (1985) on Camels Hump, VT, and Scott et al. (1984) on Whiteface Mountain, NY. Similarly, Bruck (1984) on Mt. Mitchell and Adams et al. (1985) in the mid-Appalachian forests report decline in the spruce-fir forests in the Southeast. Although considerable research is being conducted to determine the causal factors, both natural and anthropogenic, the role that atmospheric deposition plays is still unanswered. Thus the Spruce-Fir Research Cooperative (SFRC) has developed broad policy questions under the Forest Response Program (FRP) to provide information on the response of forests to atmospheric deposition.

The following are two scientific questions from the SFRC:

1. Are changes in growth and mortality and the presence of unusual foliar symptomology in red spruce-fir forests greater than those that can be attributed to typical trends and levels of natural variability?

2. What spatial patterns, if any, exist in growth and mortality and in the presence of unusual symptomology in red spruce-fir forests, and how do these patterns relate to spatial patterns of pollutant exposure?

FIBER (Solomon et al. 1987) was expanded to include a broad-base data set. The growth can be modified within the model to compare the growth response of spruce-fir trees at different years, locations, elevations, and both with and without spruce budworm (SBW) attacks. The structure of FIBER and the broad data base provide a basis for refinements that will allow predicting the growth components of the spruce-fir forest prior to known major stress from external or environmental sources.

Growth and yield research of red spruce and balsam fir forests intensified during the spruce budworm (*Choristoneura fumiferana*) epidemic that began in 1973. Under the CANUSA program, cooperative research was conducted to investigate how spruce budworm attacks altered foliage biomass and productivity of red spruce (*Picea rubens*) and balsam fir (*Abies balsamea*) trees and how these attacks affected the growth and dynamics of the spruce-fir forest. To measure the impact of growth reduction, it was necessary to develop a method of predicting stand growth both with and without stress from SBW attacks. FIBER was developed for predicting the stand growth of different tree species from data within the spruce-fir forest type prior to the onset of the SBW epidemic (Solomon et al. 1986). The transition probability equations in FIBER have been modified to incorporate the magnitude of defoliation on each species being stressed and the proportion of the susceptible species in the stand. The SFRC has the task of determining the temporal and spatial consistencies in growth, mortality, and symptomology of the red spruce and fir forest in the east and this research may provide a technique for modeling stress caused by atmospheric pollutants. Analysis of representative data with the FIBER model provides a means of addressing whether the problem of forest decline in eastern North America can be determined.

The foliage is the first point of contact between the pollutant and the tree. Simulating the effects of the different pollutants on the photosynthetic efficiencies of foliage age classes for spruce and fir would be of major importance to the growth modeling of the spruce-fir forest. Similarly, physical damage to the foliage such as from frost would also be important in carbon production and allocation. Modeling photosynthetic efficiency based on physical damage can be attempted through modification of an existing foliage production model (Hayslett and Solomon 1983).

Preliminary research has been conducted to model the relationship between the amount of current foliage produced and the existing physical changes to the foliage for balsam fir and red spruce (Solomon and Hayslett 1986). Modeling efforts have attempted to incorporate alterations in foliage production with changes in photosynthate available for translocation to the stem (Solomon 1985). Expansion and modification of this existing individual tree modeling framework should allow testing for a consistent growth response to environmental pollutants on the above ground portion of the tree.

Spruce-fir Data Base

A fundamental requirement in the analysis of temporal and spatial trends in the spruce-fir forest is the development of a data base which could be (1) used presently by scientists exploring alternative approaches to the problem and (2) used as an archival benchmark for future generations of scientific study.

Approximately 2,500 remeasured growth plots from Maine to New York were used to develop FIBER and could be used as an initial data base (Solomon and Hosmer 1986). Additional data from 1,000 plots has been added to expand the geographical base to New Brunswick and Nova Scotia, Canada. The dates of measurement range from the mid-1950's to the 1980's and cover a range of basal area, species compositions, and elevations (0-3,200 ft). This information will be supplied to the SFRC Database Management Group at North Carolina State University, Raleigh, NC, in appropriate formats and documentation for present and future use.

Temporal Variability of Growth and Mortality

Changes in forest growth and mortality usually can be attributed to typical trends and levels of natural variability. Using the data base described, we will compare forest growth over the past three decades, spanning the pre-pollution to pollution era. If significant growth declines have occurred, the magnitude of the decline and the present condition of the forest can be compared. Prediction of the natural variability within the spruce-fir forest enables us to suspect that anything beyond the expected levels is caused by alterations in environmental conditions such as from air pollution.

Subsets from the data base will be used to isolate the growth rate and stand growth response for the spruce and fir species. The subset consists of unthinned plots with 65 percent or more of the basal area in softwood species. The plots were further stratified by having at least 25 percent (basal area) of the subject species. By separating the data set into different time frames and calculating annual diameter growth rates, the different growth periods for unthinned spruce-fir stands in the Northeast can be compared.

Spatial Variability of Growth and Mortality

Spatial patterns in the spruce-fir forest will be addressed in two ways. First, an elevation variable will be tested for significance in regression equations that estimate the annual diameter growth. Residuals will be plotted over elevation to locate spatial trends. This may give important insight into possible pollution effects. However, other natural factors also are associated with elevation and, hence, caution will be used in such interpretation.

Second, spatial variables will be examined by predicting the growth in spruce-fir forests using existing data at the six different SFRC intensive sites that were not used in model development. Analyses will determine how well FIBER can predict forest spatial dynamics. The implications and possible causal factors for any unreasonable variation from the estimations will be addressed. The R^2, bias, and variance developed from the multivariate regressions within the model will be used as goodness-of-fit statistics.

FIBER Modification

The model contains nearly all the commercially important species across the New England states. Expansion of the data set will allow the model to be used for transition hardwoods that may be present in spruce-fir stands in the Northeast. In addition, the transition probabilities and regression coefficients will be modified to predict growth on an annual basis.

An initial attempt has been made to modify FIBER and test its predictability of forest growth response through time for both stressed and nonstressed species. One method of modeling extraordinary stress, such as a SBW attack, is to modify the transition probability equations.

Acid deposition data are only now being collected, so 214 remeasured, unharvested, softwood plots measured during a SBW outbreak in Maine from 1975 to 1985 were utilized (Ashley et al. 1976). A measure of projected total foliage weight remaining at the end of each 5-year period, along with the percent basal area of the species being modeled, was added to the regression equations used to predict the transition probabilities. Since the spruce budworm usually consumes the current foliage on spruce and balsam fir trees, the foliage weight remaining for a tree of a size equal to the midpoint of the diameter class was obtained by calculating the total foliage weight of the tree and partitioning that foliage into current through 6+ age classes (Baskersville 1965, Fraser et al. 1964). Average plot defoliation per year for fir and spruce was used to project defoliation for each age class. The age classes were then summed to give the total foliage remaining at the end of the projection.

The original and foliage weight variables were then regressed on the data set using an iterative-reweighted least squares regression technique with the NLIN procedure in SAS (1985). The coefficients for the original variables were forced to stay the same. The new equations were used to predict transition probabilities that account for any growth response to defoliation of spruce or fir trees.

The actual volume by species was compared to the predicted volume using FIBER before and after modification (Table 1). Between 1975 and 1985, the actual and predicted volume growth was approximately the same for all species except the spruce and balsam fir. The nonstressed version of FIBER overpredicted the volume of these species indicating the extent of volume growth reduction. The stressed version of FIBER predicted very close for spruce and fir during the first 5-year period and close for spruce during the second 5-year period. Balsam fir, however, was overpredicted for the second 5-year period. This was primarily due to the increased mortality of fir during the second 5-year interval.

Table 1.--Average actual, predicted stressed, and predicted unstressed yields (m^3/ha) for 214 softwood plots impacted by spruce budworm in northern Maine, 1975-85

Yield	Species[*]													Total	Percent Diff.
	BF	Sp	He	Ce	OS	SM	RM	YB	PB	Be	WA	As	OH		
							5 years								
Actual	39.5	67.4	10.3	24.8	4.7	1.4	8.0	4.3	3.9	0.8	0.0	2.3	1.0	168.4	
Predicted															
Unstressed	49.5	69.7	9.9	25.0	4.3	1.3	8.2	3.5	4.2	0.8	0.0	2.1	1.0	179.5	6.6
Stressed	40.4	66.5	9.9	25.0	4.3	1.3	8.2	3.5	4.2	0.8	0.0	2.1	1.0	167.2	-0.7
							10 years								
Actual	19.9	65.2	11.3	24.1	5.6	1.5	8.5	4.4	3.4	0.8	0.0	2.1	0.8	147.6	
Predicted															
Unstressed	49.8	75.1	10.7	25.1	4.4	1.5	9.0	3.6	4.2	0.9	0.0	1.9	1.0	187.2	26.8
Stressed	32.5	67.9	10.8	25.1	4.4	1.5	9.0	3.6	4.2	0.9	0.0	1.9	1.0	162.8	10.3

[*] BF = balsam fir *Abies balsamea* (L.) Mill.; Sp = spruce *Picea* spp.; He = eastern hemlock *Tsuga canadensis* (L.) Carr.; Ce = northern white cedar *Thuja occidentalis* L.; OS = other softwoods *Larix laricina* (Du Roi) K. Koch and *Pinus strobus* L.; SM = sugar maple *Acer saccharum* Marsh.; RM = red maple *Acer rubrum* L.; YB = yellow birch *Betula alleghaniensis* Britton; PB = paper birch *Betula papyrifera* Marsh.; Be = American beech *Fagus grandifolia* Ehrh.; WA = white ash *Fraxinus americana* L.; As = aspen *Populus tremuloides* Michx.; OH = other hardwoods *Betula populifola* Marsh., *Acer pensylvanicum L., Prunus pensylvanica* L. f., *Fraxinus nigra* Marsh.

One reason for overpredicting the volume may be from subjective estimates of defoliation damage. The probability of mortality of the average stand may mask the amount of stress placed upon indvidual trees and may result in overprediction of growth. It is recommended that stress history of individual trees by species within stands is necessary for models to produce a reliable and accurate prediction of mortality.

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Disease Types in Norway Spruce Stands in Southern Germany--Extent and Causes

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Abstract

The paper reviews the present state of knowledge with regard to the Norway spruce diseases and their causes in southern Germany. Four distinct disease types are described. It is demonstrated that with some diseases, pollutants and acid precipitation play a decisive role, according to the opinion of most scientists involved. On the other hand other types of disease are mainly determined by natural stress factors. All these different disease types of Norway spruce seem to be synchronized by one common trigger factor. Since diseases occur on all types of parent rock and soil and in regions, where the pollution load varies considerably, this general trigger factor is unlikely to be a pollution- or soil-induced stress. Regarding the large scale occurrence of disease phenomena all over central Europe, there is more evidence that weather stress (presumably frost events) acts as a trigger or synchronizing factor.

Extent of Damages

According to the fourth nationwide inventory of forest damage in the Federal Republic of Germany, carried out from July to September 1986, 54 percent of the total forest land was classified as damaged or diseased (BML 1986). Diseased means that the affected stands carried less foliage than normal, since the inventory technique is mainly based on an estimate of foliage losses as compared with regional "standard" conditions. Forests are classified as healthy and unaffected (damage category 0) as long as they carry at least 90 percent of the estimated normal amount of foliage. Slightly damaged stands (category 1) have foliage losses from 11-25 percent, moderately diseased ones (category 2) from 26-60 percent. Severely damaged stands (category 3) carry less than 39 percent of the normal amount of leaves.

However, the standard, or normal, situation as the basis for comparison has been inaccurately defined, and the correlations between foliage losses on the one hand and growth, vigor or physiological parameters of the trees on the other are not yet established for most species.

The distribution pattern of damage intensity reveals distinct differences between the northern and the southern parts of Germany. The forests in the South are considerably more affected than those in the North, although the concentrations of most pollutants in the atmosphere are lower. In the south, damage was highest in the eastern Bavarian Mountains along the border to Czechoslovakia, in the Black Forest and in the Alps. From 1985 to 1986 the percentage of affected forests rose in the Black Forest, with oaks (*Quercus robur* and *Q. petraea*) and with European beech (*Fagus sylvatica*). It decreased considerably in northeastern Bavaria, and in the foothills of the Alps, in Norway spruce (*P. abies*) as well as in silver fir (*Abies alba*) and Scots pine (*Pinus sylvestris*) forests. Damage intensity normally increases with age and exposure of the trees.

The most important species in Germany, in terms of acreage, production, and economic value, is Norway spruce. In summer 1986, 32 percent of all spruce forest was in the lowest damage category, 20 percent was moderately defoliated and only less than 2 percent was severely damaged or already dead. Serious defoliation was restricted to higher elevations of the so-called German subalpine mountains and of the Alps (Fig. 1).

A careful comparison of the various disease or crown damage phenomena in Norway spruce, silver fir, Scots pine, European beech, and in oak forests in the Federal Republic reveals a great diversity in symptoms, growth responses and in the occurrence of possible stress factors. Nobody seems capable, at the moment, of developing a general hypothesis covering this diversity. Therefore it is plausible to assume, as a first approach, that we have to deal with the more or less simultaneous outbreak of quite separate diseases, differing pronouncedly from species to species, and even within one particular species. Consequently we suggest that these various diseases are caused by different sets of stress factors. This approach, on the other hand, does not exclude the possibility that one common cause is involved in all those disease phenomena, but obviously with different significance and consequences.

I would like to present this specific approach describing some disease types for Norway spruce. I have chosen this particular species for demonstration because it is severely affected by diseases under a great variety of forest conditions and since several research groups have quite recently published important findings.

Death of Spruce Forests in the Ore Mountains

The Ore Mountains along the border between Czechoslovakia and the German Democratic Republic are one of the largest SO_2 pollution areas in central Europe. On exposed ridges and plateaus at elevations of more than 800-900 m a.s.l., about 30,000 ha spruce forests have been killed, mainly during the past 10 years, and have been clearcut. Even the youngest plantations are severely affected and will die within 10 or 15 years. The understory mountain ash *(Sorbus aucuparia)* trees, however, still persist on the vast clearcuts, from which all Norway spruce have vanished. Mountain ash is even capable of regenerating naturally, if enough seed trees are present. Due to the sudden decrease in transpiration after the death of the forests, the ground water table may rise, peat and bog formation starts or is accelerated.

The average annual concentrations of SO_2 in the atmosphere in the damaged areas normally exceed 40 $\mu g \cdot m^{-3}$ and often amount

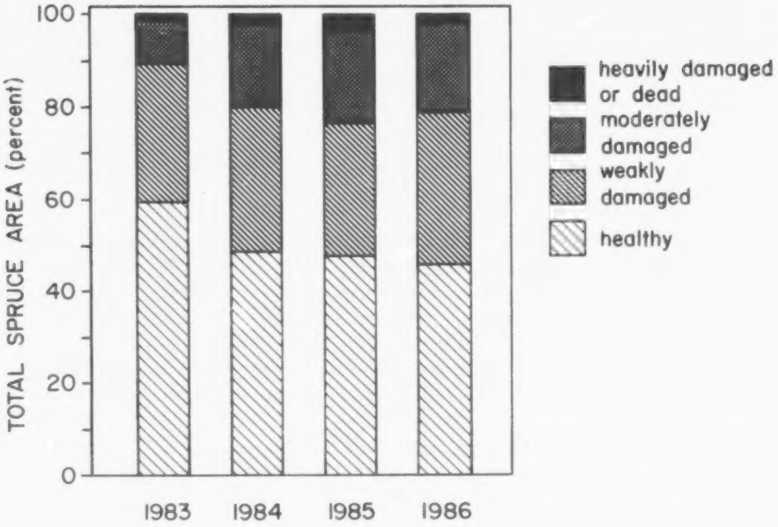

Figure 1.--Development of crown damage in Norway spruce stands in the Federal Republic of Germany (from BML 1986).

to 80 or even 90 $\mu g \cdot m^{-3}$. Therefore, in that region, classical damage of SO_2 to the foliage of evergreen conifers, disturbing mainly photosynthesis and transpiration of the trees, must be taken into consideration as the most prominent stress factor. However this factor alone cannot explain the rapid death of extensive spruce forests, which started, or was at least dramatically accelerated, in spring and early summer of 1979. According to all knowledge about the effects of SO_2, mean concentrations between 40 and 80 $\mu g \cdot m^{-3}$ can induce a substantial decrease in vitality and growth and even the death of individual trees, but not the more or less sudden mortality of thousands of hectares of spruce forests. Therefore, all our Czechoslovakian colleagues unanimously ascribe this type of damage to the combined action of SO_2, directly affecting the needles, and of frost shocks, causing the spruce forest catastrophe. According to their findings the decrease in soil fertility through the impact of acid deposition from the atmosphere, although present, is not a prominent stress for the trees. Proton deposition in the Ore Mountains is estimated to amount to up to 8-10 $kmol \cdot ha \cdot a^{-1}$.

Norway Spruce Disease at Higher Altitudes on Acidic Soils in Germany

Since 1980 an apparently new disease of Norway spruce has been observed at higher altitudes of the German subalpine mountains on acidic soils derived from crystalline parent rock or from sandstones. This disease type occurs for example, in the Bavarian Forest as well as in the Black Forest, generally at elevations of more than 700 m above sea level (Bosch et al. 1983, Zech and Popp 1983, Zöttl and Mies 1983).

The disease starts with a pronounced yellowing of older needle age classes, followed by necrosis and shedding. This leads to a marked transparency of the crowns, mainly at the center and base. Only the older foliage is chlorotic; the youngest shoots are normal green. The discoloration starts at the tips of the needles, while the needle base remains green .The gold-to-yellow chlorosis is generally much more severe on the upper side of the needles and branches than on the lower, and is characteristic of severe magnesium deficiency.

Direct effects of SO_2 on spruce foliage can be ruled out as a plausible stress factor. The concentrations of this pollutant in the ambient air (10-15 $\mu g \cdot m^{-3}$ annual average) are well below the IUFRO limits for damage.

The disease affects old stands as well as young trees. A long term growth depression was detected as a characteristic feature. A pronounced tree-to-tree and stand-to-stand variation of disease intensity occurs on the same soil. Autochthonous populations in the subalpine spruce belt of the Bavarian Forest are suffering considerably less than obviously foreign spruce provenances which were introduced, presumably from lower elevations, on to vast clearcut areas or to former pasture land.

The apparently healthy, as well as the diseased trees, are very well supplied with N and P, and adequately with K. There is no indication of Cu, Mn or Zn deficiency or toxicity. The foliar contents of these elements are low. If a significant difference shows up in the Cu, Mn or Zn nutrition between affected and control trees, the latter are always superior. The Cd, Pb, Ni and Cr contents in the needles of all disease categories are extremely low. The S, Cl, F, and Al levels are far from critical.

The most striking and consistent difference arising from our comparison of diseased and healthy spruces, as well as from the

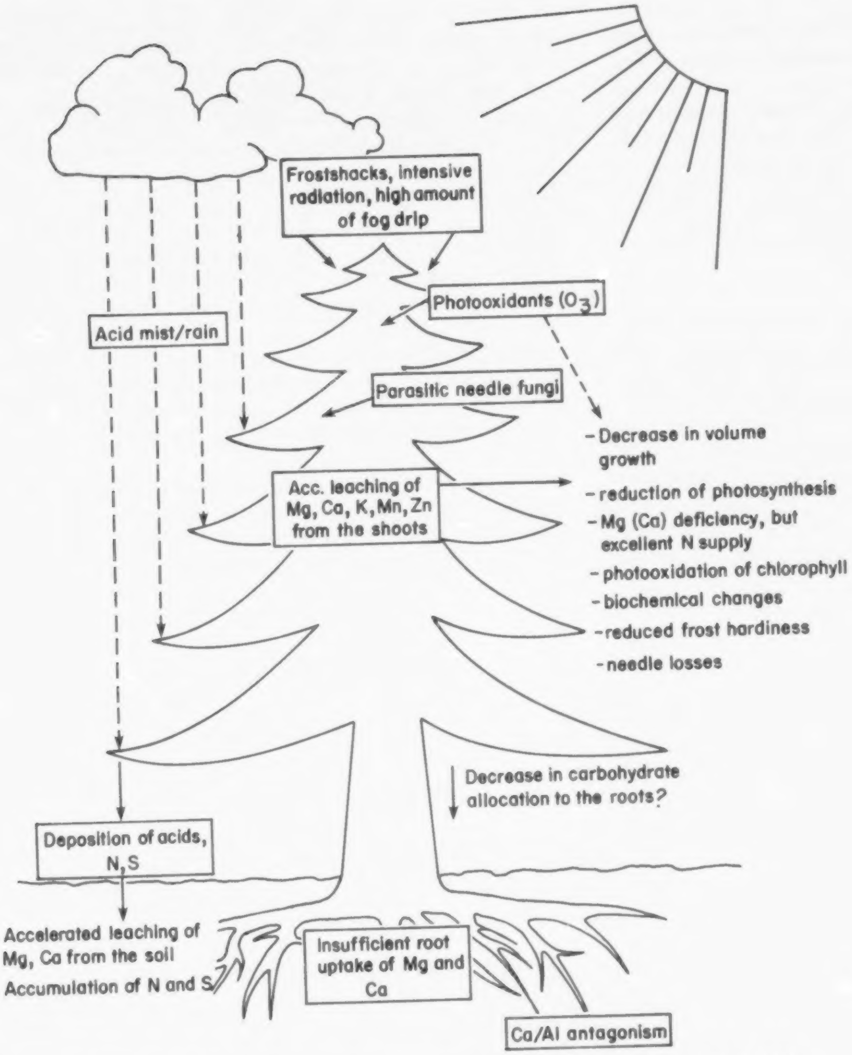
Frostshacks, intensive radiation, high amount of fog drip
Photooxidants (O_3)
Acid mist/rain
Parasitic needle fungi
- Decrease in volume growth
- reduction of photosynthesis
- Mg (Ca) deficiency, but excellent N supply
- photooxidation of chlorophyll
- biochemical changes
- reduced frost hardiness
- needle losses
Acc. leaching of Mg, Ca, K, Mn, Zn from the shoots
Decrease in carbohydrate allocation to the roots?
Deposition of acids, N, S
Accelerated leaching of Mg, Ca from the soil
Accumulation of N and S
Insufficient root uptake of Mg and Ca
Ca/Al antagonism

Figure 2.--Working hypothesis to explain Norway spruce decline on acidic soils at high altitudes of the mountainous regions (according to Rehfuess and Bosch 1986).

investigations of other colleagues concerned Mg and Ca. The level of supply is in general rather poor, even with healthy trees, but the diseased spruces always have lower foliar concentrations of both elements and suffer from extreme Mg deficiency. Needle analysis thus supports the foliar symptoms.

Affected stands occur on soils which are moderately acidic, but obviously not more acidic than they were 20 or 30 years ago. The pH (H_2O) values in the mineral horizons range from 4.5 to 5.0., Magnesium deficiency of spruce was observed on soils derived from granite very poor in Mg. It also occurs on soils derived from paragneiss or even metagabbro with high contents of total Mg throughout the solum. The contents of exchangeable Mg however, are always very low in these more or less podsolized soils (< 50 $\mu g \cdot g^{-1}$ dry soil). Thus scarcity of readily available Mg is one important precondition for this particular disease type.

Looking at the needle surfaces by scanning electron microscope we occasionally observed gypsum ($CaSO_4$) crystals, which were more frequent on green than on yellow needles and occurred predominantly in or around the stomatal cavities. All the available observations and a series of experiments lead to the conclusion, that the Ca part of the crystals must originate from the interior of the needle and was not deposited on the needle surface from the atmosphere. Green needles in November consistently had more raffinose, but less starch than chlorotic ones, and this difference may indicate a higher frost resistance at the time of sampling (Bosch et al. 1983). In spring 1985, in an affected stand, we observed frost injury symptoms only on yellowish branches and not on green trees. All these findings were combined to develop the following working hypothesis about the causes of the high altitude disease of Norway spruce in southern Germany (Rehfuess and Bosch 1986) (Fig 2):

During fine, sunny weather in summer, intensive formation of ozone and other photooxidants may occur at higher elevations, where the radiation is high and where the precursor pollutants like nitrogen oxides and hydrocarbons are transported from the emission sources down in the valleys by winds blowing up slope during the day. The photooxidants may cause some deterioration of the cell membranes and cuticular waxes, making them more permeable to cations (Magel and Ziegler 1986). Later on, the mountain summits are again covered by clouds for long periods. During cloud drip precipitation events, acid mist with pH values down to 2.6 will efficiently leach cations like Mg and Ca from previously damaged needles. In the long run this may cause Mg deficiency, provided the trees are not capable of compensating for those leaching losses by uptake from the soil. The root absorption of Mg and Ca is restricted on acid substrates because the readily available amounts are rather low. These amounts may even be diminished via accelerated leaching from the soil by increased acid deposition. The proton input in throughfall at these sites ranges from 1-2 $kmol \cdot ha^{-1} \cdot a^{-1}$. High contents of exchangeable A1 - which have long been present in these soils - will antagonize the root uptake of Mg and Ca. The Mg deficiency of the trees slows down their photosynthetic capacity and volume growth and may decrease frost hardiness in particular. That is presumably the reason why the damage, latent at first, suddenly became evident after a series of severe frost shocks between 1979 and 1983, when strong convectional frosts occurred after extended periods of mild weather (Fig. 3).

The intensity of this specific damage must be highest at the summits of the mountains, where the O_3 concentrations show peak values during periods with intensive radiation, the number of fog days is highest, photooxidation of the chlorophyll is

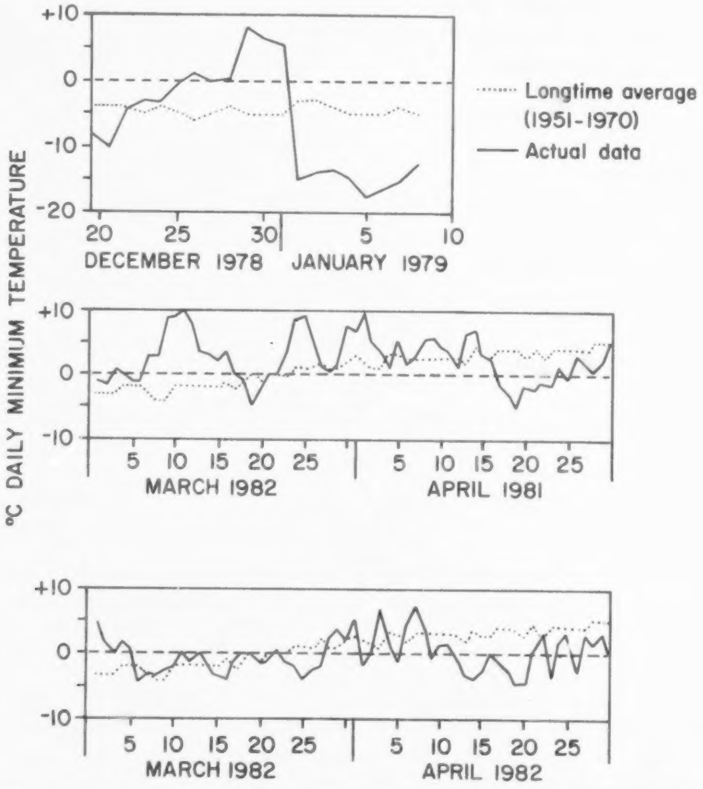

Figure 3.--Documentation of a series of frost shock events between 1979-1982 at the weather monitoring station München-Riem (Rehfuess and Rodenkirchen 1984).

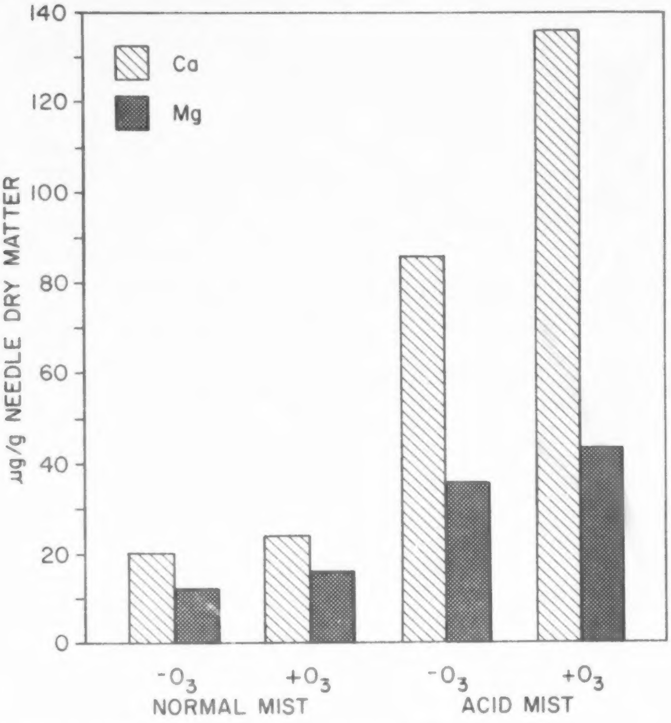

Figure 4.--Leaching of Mg and Ca by mist from spruce crowns under normal climatic conditions (Averages for treatments fertilized and not fertilized with MgCa; Bosch et al. 1986).

intense, many soils are rather poor in readily available Mg but provide plenty of N, and frost events are frequent. The involvement of frost among the stress factors offers an elegant explanation for the striking tree-to-tree and stand-to-stand variation of damage intensity in the affected regions, since it is well known, that the frost resistance of conifers is closely controlled by genetic factors.

This working hypothesis is currently under test in experiments at various research institutions. The preliminary results of a pilot trial were published recently (Bosch et al. 1986, Magel and Ziegler 1986). It was conducted in newly established climate and exposure chambers of the GSF at Neuherberg/Munchen (Payer et al. 1986). Four-year-old saplings of a Norway spruce clone, growing either in a Mg and Ca deficient soil or in the same substratum fertilized with Mg and Ca were subjected to different treatments with 0_3 and mist. Spraying with acidic mist (pH 3.0) increased foliar leaching of Mg and Ca significantly (Fig. 4). Trees growing on a soil well provided with readily available Mg and Ca, however, were able to maintain an adequate Mg supply (Fig. 5). In contrast, on a substratum poor in Mg and Ca, acid mist treatment together with exposure to high 0_3 levels was associated with extreme Mg deficiency of the spruce saplings (Fig. 6). The frost hardiness of Mg deficient trees was 2-5°C less than that of specimens well provided with this element. In another experiment, Brown et al. 1986 have demonstrated interactions between the genotype of Norway spruce saplings, fumigation with 0_3, and their frost hardiness. Consequently, some experimental evidence is already available to indicate that at least parts of the working hypothesis described above may hold true (Rehfuess and Ziegler 1986).

Needle Reddening of Older Norway Spruce Stands in Southern Germany at Lower Elevations

In late autumn of 1982, the sudden outbreak of another specific disease type occurred in older Norway spruce stands at lower elevations all over southern Germany. This disease type in fact seems to be the most widespread in the South (Rehfuess and Rodenkirchen 1984, 1985).

The symptoms were as follows: Most stands looked healthy and perfectly green during the whole summer. Starting in late September, several age classes of older needles simultaneously began to change their color to red within a fortnight. This needle reddening occurred at the edges of the stands as well as in the interior. We observed it in very vigorous and fast growing stands on fertile soils and in suppressed and starving spruces on very acidic substratum under the overstory of pine or larch. The red needles showed black dots and bars indicating heavy infestations

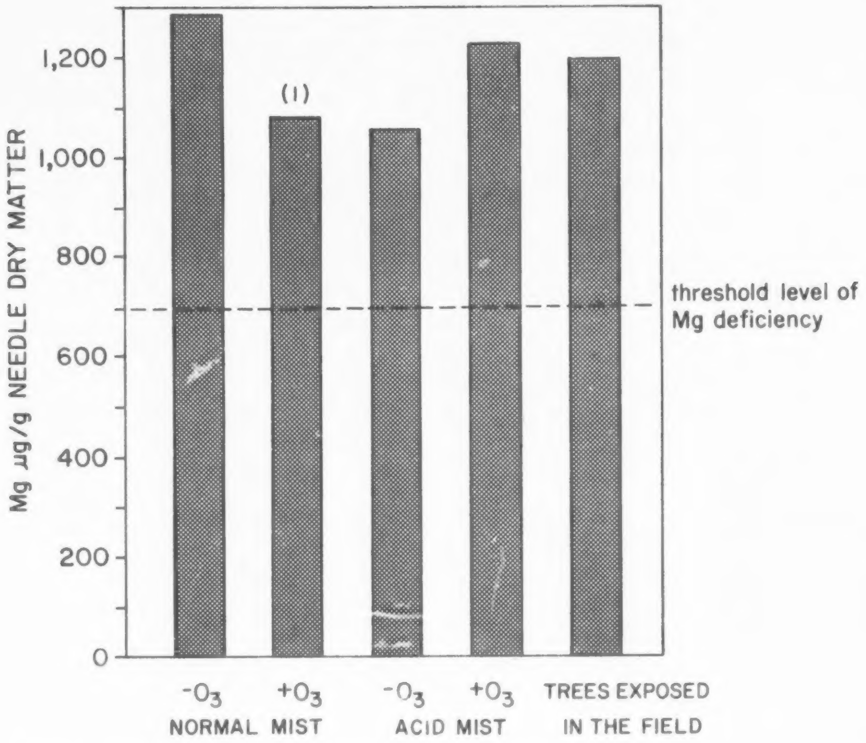

Figure 5.--Foliar Mg contents of spruce saplings fertilized with MgCa at the end of the exposure experiment (needle age class 1984; composite samples). (1) = value corrected for change by mistake of two trees (Bosch et al. 1968).

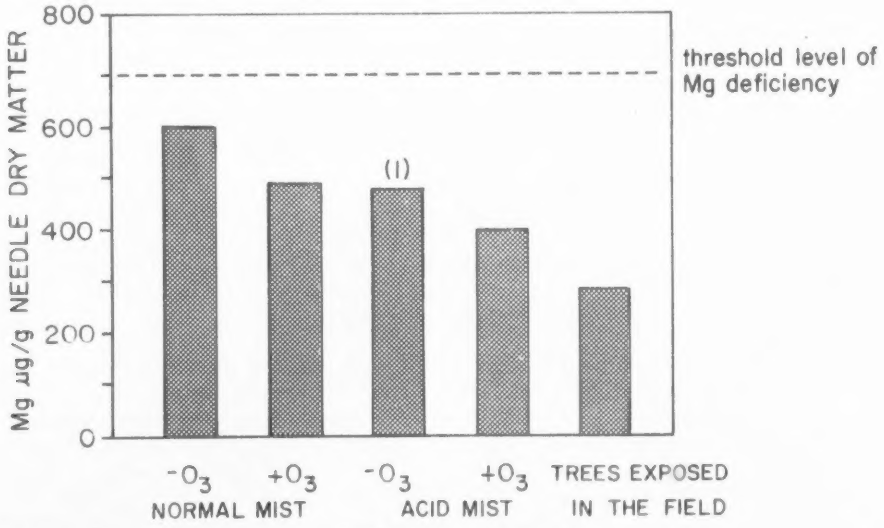

Figure 6.--Foliar Mg contents of unfertilized spruce saplings at the end of the exposure experiment. For comments see Fig. 5.

by two species of needle cast fungi *(Lophodermium piceae* and *Rhizosphaera Kalkhoffii*). The needles were shed from the branches during November or December. The secondary branches lost most of their older foliage towards the base of the shoot, and the so-called "silver tinsel symptom" appeared on comb type spruces, with secondary twigs which hang down perpendicularly from the main branch. The outer mantle of the crown remained green and was built up from the 4 or 5 youngest age classes of needles. The crowns got more and more transparent in their inner and basal parts, since the needle reddening process was repeated during 2 or 3 subsequent years. As soon as the affected reddish-brown needles are shed, there are no further symptoms than loss of older foliage. Growth depressions are observed only if the foliage losses exceed 40-50 percent.

Until now this disease has only seriously affected stands which are older than 60 years. So one can find very poor looking old trees side by side with healthy plantations on exactly the same site. No long term growth reduction has been detected in spruce stands suffering from this disease. Another observation is still more astonishing: In the foothill region of the calcareous Alps, silver fir, which is known to be the most susceptible of all tree species with regard to pollutants, shows healthy growth, whereas spruce in the immediate neighborhood is severely affeced by foliage losses.

Needle reddening and fungal infection occurred on all types of parent rock and soil in southern Germany. In contrast to other disease types, no correlation exists between the nutritional status of the trees and the occurrence or intensity of damage. For most stands we can rule out SO_2, NO_x, fluorides, chlorides, heavy metals, photooxidants or acid deposition as general stress factors. The disease occurs for example, in the Lake Constance region, where an annual proton deposition of 0.1 $kmol{\cdot}ha^{-1}$ was determined. All observational evidence points to the conclusion that we are dealing with a conventional needle cast disease or epidemic, which was already described in the literature by Hartig (1889) about 100 years ago and which seems to be mainly determined by weather factors. We speculate that a series of frost shocks in the late 1970s and early 1980s (Fig. 3) may have caused sublethal damage to the older needles. The infestation of those predamaged needles by secondary needle parasites may have been favored subsequently by high rainfall and high air humidity in early summer. This assumption of an episodic interaction of frost shock events and common pathogens is supported by another striking feature of this disease type:

One observes the initiation of an intensive recovery process. On the upper side of the main branches new shoots are formed. The trees obviously try to compensate for the severe foliage losses by forming adventitious branches. These recovery shoots started to grow in 1982 or 1983, they sprouted and branched vigorously in 1984 to 1987. In the formerly diseased stands one can still observe the naked "silver tinsels" of the older secondary branches hanging down sadly. The main branch, however, is already densely covered by new recovery shoots. In the fall of 1985 and 1986, needle reddening and fungi attack occurred again, but they caused only minor needle losses. In all these years needle reddening did not affect the recovery shoots, but was restricted to the oldest branches. So we can really hope that this disease type will disappear quite soon.

Norway Spruce Disease at Higher Elevations of the Calcareous Alps

At higher elevations of the Calcareous alps in southern Bavaria, mainly built up from limestones and dolomites, rather sudden decrease of vigor in Norway spruce stands and the appearance of decline phenomena started in about 1981 on south-facing slopes. The decline is accompanied by chlorosis and premature shedding of older needles, and the crowns again become increasingly transparent. In general, old and young trees are affected similarly. Spruce exhibits symptoms of Mn deficiency, namely a yellow to pale discoloration of the youngest shoots. It also suffers from K deficiency as indicated by a yellow-tip chlorosis of older needles. In contrast to the trees on acidic soils in the Bavarian Forest, the needles contain plenty of Mg and Ca, whereas the supply of N and P is rather poor. This very specific nutritional status can be explained by the soil conditions. The stands are growing on shallow, stony or even rocky soils derived from dolomite on steep slopes of southern aspect and in ridge positions. These soils show alkaline reaction. They are extremely rich in Ca and Mg but poor in available manganese and potassium. Soil acidification cannot be a stress factor under these conditions, since the amount of acids deposited from the atmosphere is low (1-1.5 kmol $H^{+}{\cdot}ha^{-1}{\cdot}a^{-1}$ in throughfall) and since it is imported into well buffered soils. In spite of high annual precipitation, periods of water stress are common as a consequence of the low water holding capacity of the substrate. Frequent desiccation of the soils will decrease the availability of N, P, and K. Well known root rot fungi like *Heterobasidion annosum* and *Armillaria mellea*, and secondary needle fungal parasites are also involved.

It is my feeling that this disease type, occurring on calcareous soils in fairly unpolluted regions, is at least partly caused by extreme edaphic conditions and by weather events like dry spells and/or frost shocks, pushing the less vigorous older trees toward disease or rapid death. However, there are two pollution factors which could also play a significant role: the interaction of ozone and other photooxidants on the one hand and the direct impact on the foliage of episodic acid precipitation events on the other.

The consequences of a true and long lasting decline of old spruce stands in the Alps would be extremely dangerous, because the natural, as well as the artificial, regeneration of these forests is made impossible over extended areas by an overpopulation of roe and red deer. It is only in these areas that the existence of the forest is really in danger and that there is a potential, in the long run, of the formation of avalanches, land slides and of erosion.

Conclusions

A comprehensive review of the time courses and symptoms of the recent "damages" in Norway spruce stands shows that at least four separate disease types occur in southern Germany. All of them lead to drastic needle losses (mainly from older age classes) and to transparency of the crowns. The sets of plausible stress factors associated with each of these disease types differ pronouncedly. There are some diseases in which pollutants and acid precipitation are playing a decisive role. Others are mainly determined by natural stress factors. All these different disease types of Norway spruce seem to be synchronized by one common trigger factor. Since diseases occur on all types of parent rock and soil and in areas where the pollution load varies considerably, the general trigger is unlikely to be a pollution- or a soil-induced stress. Regarding the large scale occurrence of disease phenomena there is more observational and even experimental evidence that weather stress acts as synchronizing factor. Principally either drought, frost, or frost shock events could induce the more or less simultaneous outbreak of different diseases. Searching for extreme weather situations all over central Europe during the period in question (1981-1984) leads to the conclusion, that frost shock events are presumably responsible for the synchronizing effect (Rehfuess 1985, 1986).

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Forest Decline in Germany

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Three questions are to be answered from a personal perspective. In my case they are discussed from the point of view of a forest botanist and pathologist. In order to find a joint base of discussion, please let me start with a number of definitions and characterizations of what we call "Waldsterben" or "neuartige Waldschaden", "forest decline" or "forest damage":

Two different kinds of basic philosophies can be distinguished at the moment:

- Waldsterben is explained as a disease of forest ecosystems
- It is a number of single well-known tree diseases, which simultaneously occur at the same locations by chance.

I prefer the first way of thinking and the following considerations are based on this supposition. Beyond that, a number of peculiarities are found to be typical for the Waldsterben-syndrome, and they are not in harmony with the behaviour of common diseases:

- Waldsterben is a new phenomenon, which appeared suddenly
- It spreads rapidly
    -geographically (almost over the entire northern hemisphere within 8 years)
    -biologically (most tree species in Europe are affected, also several shrubs and herbs)
- It is not restricted to
    -certain geological conditions
    -climate
    -soil conditions
    -methods of forest management (silvicultural methods)
- It is explained with air pollution effects, although "classical pollutants" cannot be the primary causes.

From a pathological point of view it has to be added, that Waldsterben obviously belongs to the range of complex diseases, where more than one pathogenic effect has to occur simultaneously or sequentially. This means we have to consider primary and secondary causes.

Out of these items, out of many additional observations, from research data and literature studies, we have developed a working hypothesis which is summarized in a few sentences. Permanent exposure to low concentrations of air pollution, composed of an unknown number of phytotoxic compounds and transported over long distances leads to reduced vigor of trees and also affects other members of the ecosystem. It's manifested in lower production or lower availability of carbohydrates and secondary plant substances. This again increases the predisposition to climatic extremes and pathological events.

The development and the reproduction ability of the fine root system is affected, the mycorrhization and the nutrition of the tree disturbed. The longer these influences last, the more pronounced is the transparency of crowns and the deterioration of fine roots.

This hypothesis is able to explain the majority of symptoms in many species:

- It makes it understandable that primary and secondary symptoms occur in many cases
- It explains why it is useless to search for a still unknown pathogen which is able to attack dozens of different conifer and broadleaf species on both sides of the Atlantic
- It shows that we need not find climatic extremes, which occurred in southern Italy, central Sweden and on Mt. Mitchell at the same time
- It explains why local differences in symptom expression and disease severity can occur.

There is one disadvantage, however: it fails to present one single cause responsible for the whole syndrome. That's the reason why neither the public, nor the politicians, nor many of my colleagues like this hypothesis.

As a matter of fact - the hypothesis is neither spectacular nor sophisticated. It's just plain good old pathology.

But one fact is new:
The causes are man-made. And they hit a biological system that has not been confronted with them before.

To sum it up:
We assume that hundreds of toxic compounds, one by one or in combination, synergistic or not, burden an ecosystem on thousands of unknown reaction points, and this for dozens of years. Please, just for a minute and only theoretically accept this assumption. And then try to establish a research program to prove it. Pretty soon you will see big, big obstacles.

1. Ecosystems cannot be pressed into artificial test systems like chambers or phytotrons.
2. Field experiments with entire ecosystems are likewise impractible.

3. The composition of ambient air pollution is only known for a handful of components like SO_2 or O_3. Besides numerous volatile exudates from foliage, however, thousands of anthropogenic components are present. Since they change with time and location, the situation is hardly reproducable and therefore not to be used for experimental purposes. Experimental results with single components are interesting but of little relevance with respect to the causes of Waldesterben.

4. Waldsterben normally starts in old trees. Until now it has not yet reached younger age classes. This fact makes realistic experiments almost impossible.

5. Under these assumptions even Koch's postulates are not applicable, at least not at the moment, because (a) a single, clearly defined causal agent does not exist; (b) a multifactorial ecosystem as a host never reacts in a predictable way.

Under these circumstances it is little surprise to me that Waldsterben research has not been very successful in the past. In addition to these more general aspects, the history of Waldsterben research has some peculiarities of its own, which from my point of view have inevitably led to false and inefficient activities.

- Forest decline, there is no doubt about it, has much to do with trees and forests. Consequently foresters, more than others are able to see it, to feel it, to judge it. At least in our country, they are fairly under-represented on the boards of research funding and planning.

- Forest decline is also a disease. Therefore the rules of pathology have a special and direct meaning. These rules tell us, that all research in disease etiology has to start with an intense study of symptoms. This golden experience has been ignored by Waldsterben-programs in more than one country. It's often an open question whether researchers are talking about the same phenomenon. As an example, a number of hypotheses are based on very special criteria in one species only, restricted to special regions.

- Other hypotheses do not even mention a symptom.

- Secondary symptoms are often interpreted as primary ones. Without the advice of experienced pathologists things sometimes run in the wrong direction.

- Up to now we cannot be sure whether or not forest decline in the United States and Waldsterben in Central Europe is the same phenomenon. It's high time to prove it. How else can it be done than with a tool named symptomatology?

We are all aware, and it is deeply acknowledged, that Waldsterben research started with remarkable activities in monitoring wet and dry deposition. We had dozens of projects on the effect of acid rain on soil chemistry, on leaf surfaces and on nutrient uptake. We also learned quite a bit about the detrimental effects of ozone on the cytology and physiology of leaves. But we seldom focussed these investigations precisely on cases which, for sure, belong to the Waldsterben-syndrome. So I wish you would keep this sentence in mind: Take symptomatology seriously and do not take the second step before the first.

My second and even more basic concern:

Waldsterben probably is the most serious and complicated threat forests were ever exposed to. Many biotic and abiotic parts of forest ecosystems are affected. Under these conditions a well-prepared, far-reaching national and international research strategy, is of central importance. What is practiced in reality is kind of jumping from one favourite component to the next: SO_2 - Acid Rain - Ozone - frost - photooxidants - organic compounds. If we will ever succeed in solving this problem - then by chance. What I wish to stress is: Research strategy has first rank, made by professionals, not by politicians and not by administrators. And this strategy has to be transferred into an international system of coordination. Immediately, if you ask me. Otherwise, Waldsterben research most probably will remain what it presently looks like: Molecule Brownian motion - very active but without direction and progress.

Forest Decline in the Federal Republic of Germany

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Abstract

Forest decline in the Federal Republic of Germany started mainly with Norway spruce in Southern Germany in 1980, and 1982 elsewhere. First symptoms of decline of silver fir were already detectable as early as 1976. Between 1985 and 1987 there was a considerable increase in decline of deciduous trees, especially of European beech. Unlike coniferous trees, the symptomatology and causality of the decline of deciduous trees are still very unclear.

The obvious, most important symptom of decline of Norway spruce is needle chlorosis combined with magnesium deficiency. According to the current state of knowledge, the combinatory effect of poor nutrient status in the soil, caused by geology and acidic deposition, on the one hand, and ozone and acidic fog exposure on the other is the most probable explanation of this novel form of forest decline.

Development and Spatial Distribution of Novel Forest Decline

Within Europe, West Germany is among the countries most affected in recent years by forest damage. All inventories show damage concentrated mostly in southern Germany, south of the Main River (Figure 1). The neighbouring parts of surrounding countries, especially countries to the south like Austria, Switzerland, and France, are also damaged.

Several different species of trees (coniferous and deciduous) are involved. It appears that silver fir *(Abies alba)* first showed apparent symptoms of decline in the mid-1970's, followed by Norway spruce *(Picea abies)* in 1980 in southern Germany and elsewhere in 1982, and some deciduous species such as European beech *(Fagus sylvatica)* and oak *(Quercus* sp.) in 1984 and 1985. With respect to the severity of symptoms and distribution of damage, Norway spruce seems to be the most important. Although more severely damaged, silver fir stands are concentrated in relatively small areas, especially at higher altitudes of the southern German subalpine mountains, so that this type appears to be less important overall.

In Norway spruce, the main symptoms are needle chlorosis, which increases with elevation of the stand, and thinning of the crown, which occurs more at lower elevations and in the plain. With respect to specificity, intensity, and distribution, needle chlorosis in the higher elevations of the subalpine mountains is considered as the really relevant type of damage of Norway spruce. Moreover, the greatest amount of scientific information is available for this type of damage.

Needle chlorosis can be clearly associated with deficiencies of nutrients in the tree, especially deficiencies of magnesium (Figure 2), calcium (see Figure 3), zinc, potassium, and manganese. The supply of other nutrients, especially nitrogen and phosphorus, is, on the whole, sufficient. At some sites where damage is especially severe and which are far from industrial and urban centres, even the concentration of sulfur is significantly lower in yellow needles than in green needles, reaching the range of deficiency of this essential element. This is an important observation for causality in implicating leaching rather than sulfur toxicity as a factor. Only needles exposed to the sun turn yellow.

Older trees are affected more by chlorosis than younger ones. Stands with trees of varying ages and varying types with a rough canopy are more affected than even-aged and uniform stands with a closed canopy.

As already explained, it is most striking that the intensity of needle chlorosis is very much dependent on elevation (Figure 4). Furthermore the damage is not concentrated in the, with respect to sulfur dioxide, highly polluted areas of Rhine and Ruhr but in the remote areas of the Black Forest, the Bavarian Forest and other subalpine mountains. So any causal factor which is brought into discussion has to fit this temporal and spatial pattern.

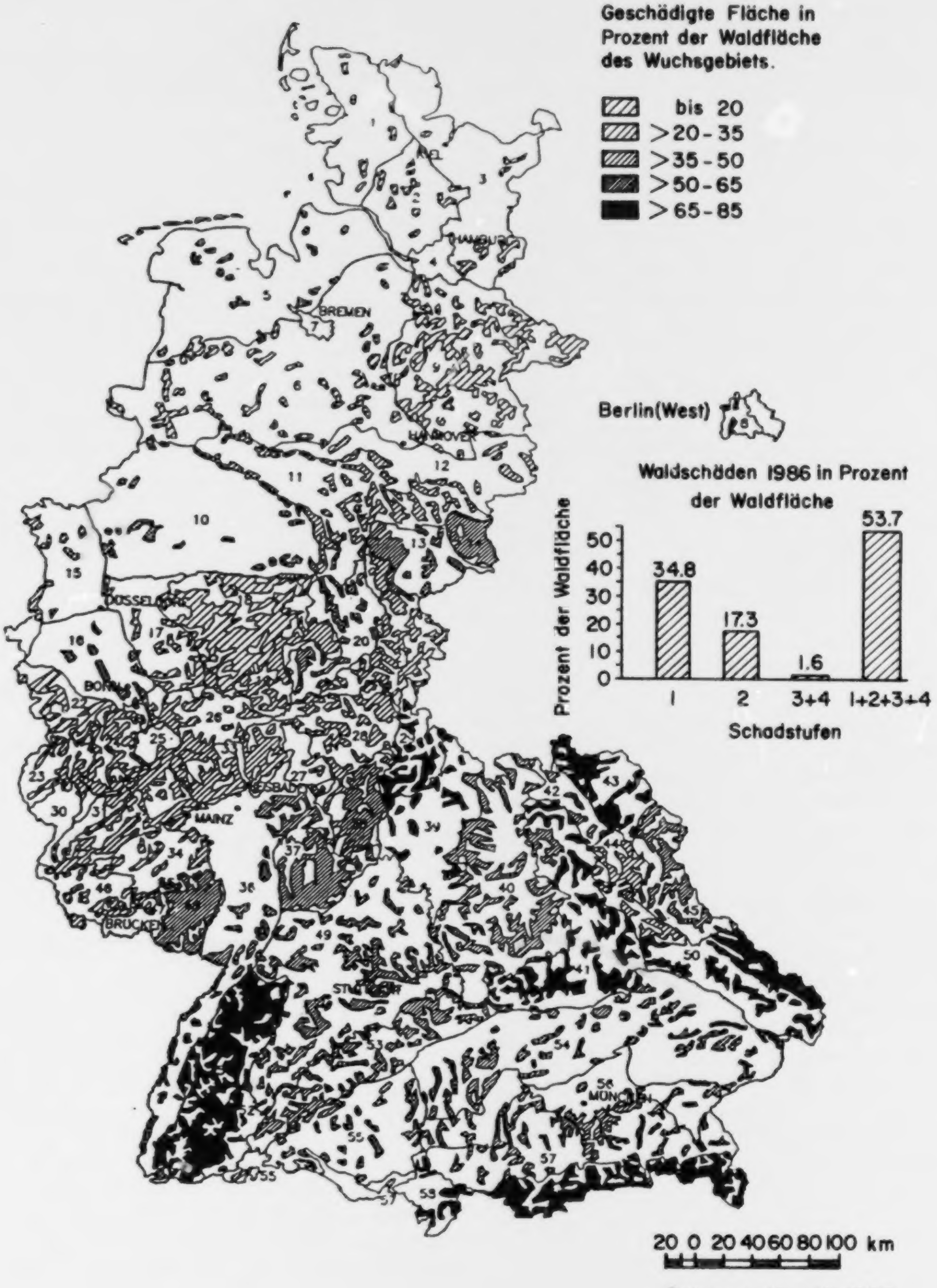
It has to be added in this connection that there is a clear preference for needle chlorosis on magnesium deficient, acidic soils. On the other side, however, forest decline is not strictly limited to a specific bedrock. At least the dependency on altitude is much stronger than on any soil condition or bedrock situation. So the soil is considered to be an important accompanying factor in the causation of forest decline but not a decisive one.

Poor soil conditions, caused by bedrock and land management, also existed in the past. But forest decline has never reached such dimensions in space and time like now. The discussion has to concentrate on the crucial point why this phenomenon happened just now and why it happened just in the existing spatial variation.

One of the first descriptions of the phenomenon of novel forest decline and attempts to explain it were undertaken by PRINZ et al. 1982. Since that time much literature has been published. For further details, and under a rather subjective view, the following references are given (Prinz et al. 1985, Prinz et al. 1987, FBW 1986, Prinz 1987, Krause 1987, Krause 1988).

Evidence for and Against the Role of Atmospheric Pollutants

Each attempt to explain the cause of forest decline has to start with the phenomenological aspect. Furthermore it has to consider


Geschädigte Fläche in Prozent der Waldfläche des Wuchsgebiets.
bis 20
>20-35
>35-50
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>65-85
Berlin(West)
Waldschäden 1986 in Prozent der Waldfläche
Prozent der Waldfläche
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50
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53.7
1
2
3+4
1+2+3+4
Schadstufen
KIEL
HAMBURG
BREMEN
HANNOVER
DÜSSELDORF
BONN
WIESBADEN
MAINZ
SAARBRÜCKEN
STUTTGART
MÜNCHEN
20 0 20 40 60 80 100 km

Daten zur Umwelt 1986
Umweltbundesamt

Figure 1.--Distribution of forest decline (all damage classes of all tree species) in the Federal Republic of Germany in 1986. The damage areas are presented as a percent of the forest area within individual growing districts No. 1 to 53 (BML 1986).

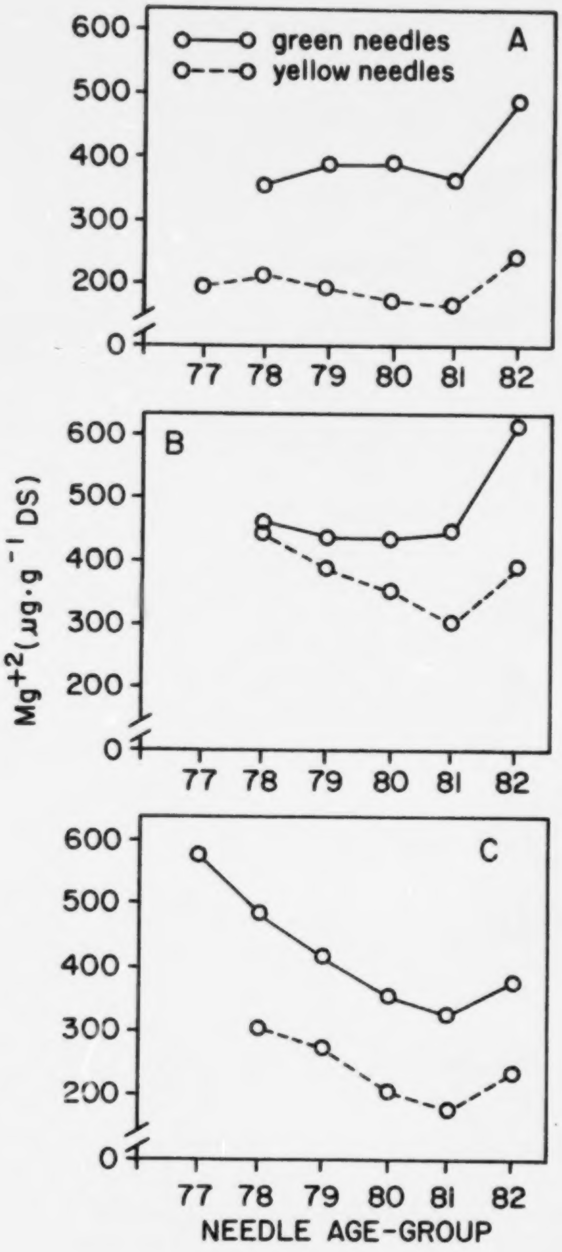

Figure 2.--Concentration of magnesium in needles of Norway spruce with different degree of discoloration. Samples were taken from three different stands in Baden-Wurttemberg (A) und North Rhine Westphalia (B and C) (Prinz et al. 1982).

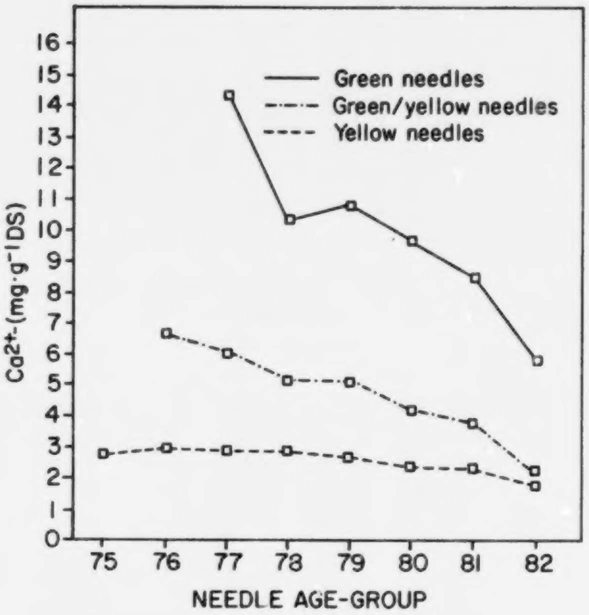

Figure 3.--Concentration of calcium in needles of Norway spruce with different degree of discoloration from a stand in Baden-Wurttembertg (Prinz et al. 1982).

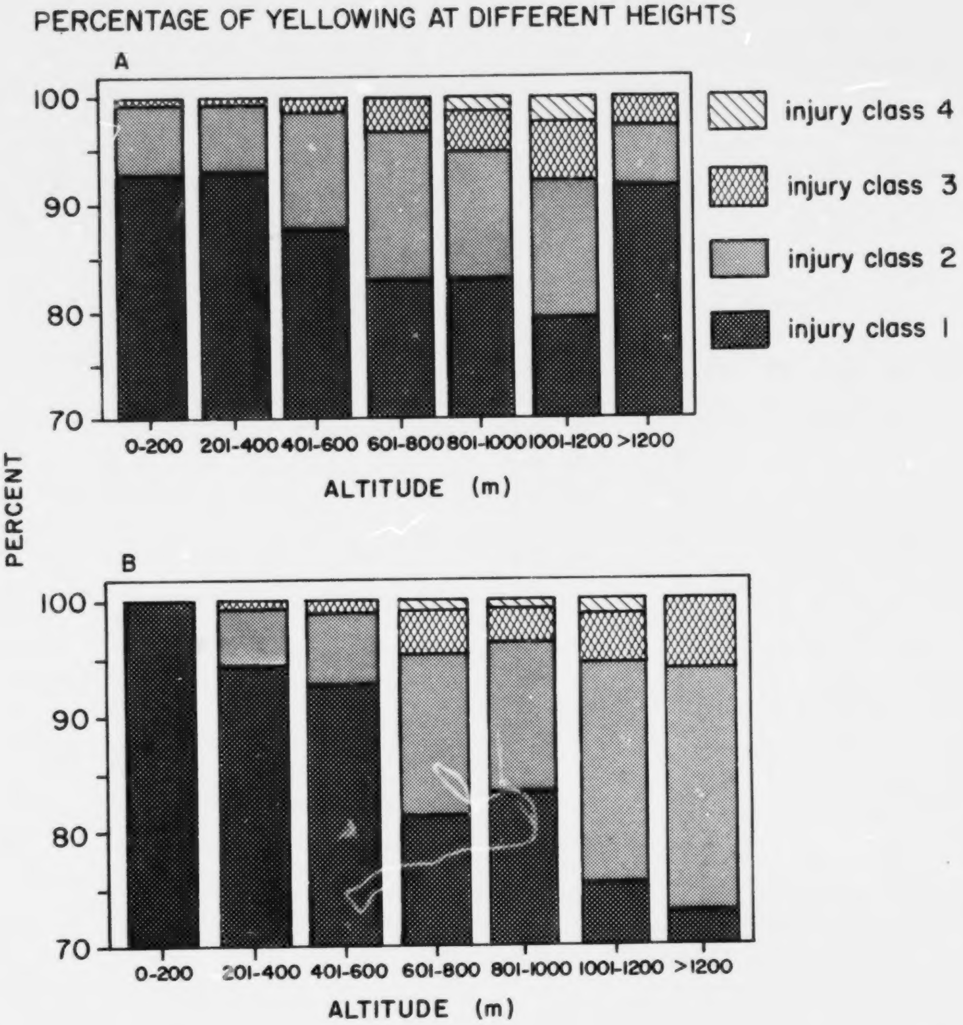

Figure 4.--Percentage of stands of Norway Spruce with discoloured needles dependent on elevation. The situations in the states of Baden-Wurttemberg a) and Bavaria b) are presented as two prominent examples. The steps 1 to 4 mean 0% - 10%, 11% - 25%, 26% - 60%, and 61% - 100% discolouration (FBW 1986).

that plants react to a lot of different factors at one time. Unfortunately sufficient information is only available for Norway spruce and silver fir. Because of its limited distribution, however, Silver fir is of minor importance.

As already explained, the typical symptom of the decline of Norway spruce is yellowing of older needles, combined with deficiency of cationic nutrients, especially magnesium. Magnesium deficiency and chlorosis start synchronously in the previous years' needles with the budding of new needles in springtime. A second step is observable in late autumn. The preference of damage to mixed stands with rough canopies has already been mentioned.

Histologically, the phloem seems to be especially affected. The assimilation rate is reduced mainly by loss of chlorophyll and not so much by malfunction of the remaining chloroplasts.

The change of environment during the last decades as possible causes for the described phenomenon concerns the following factors:

Climate. Dry, warm summers with long periods of sunshine in 1975, 1976, 1980, 1982, modified by regional influences. In North Rhine-Westphalia, for example, also the summer in 1983 was dry, warm and sunny.

Air pollution. Decrease in emissions of sulfur dioxide and most other pollutants, but increase in nitrogen oxides emission. Increase in ambient nitrate deposition and photooxidants. Perhaps also increase in ammonia deposition. At least during the last 20 years no further increase in rain acidity. The only component with a clear relationship to spatial distribution of chlorosis of spruce is ozone. This component clearly increases in concentration with increasing distance from source areas and with increasing altitude. Also of importance is acidic fog with different composition than rain in the higher elevations.

Soil. Obvious loss of buffer capacity and nutrients, with the exception of nitrogen, during the last decades, due to harvest of biomass and acidic deposition. It must be mentioned, however, that no real time-series analysis exists for soil acidification. More data result from reexaminations of the soil immediately after damage had been discovered, i.e. in dry warm summers after 1980. This is of importance because strong, climatically induced variation of soil pH is well known.

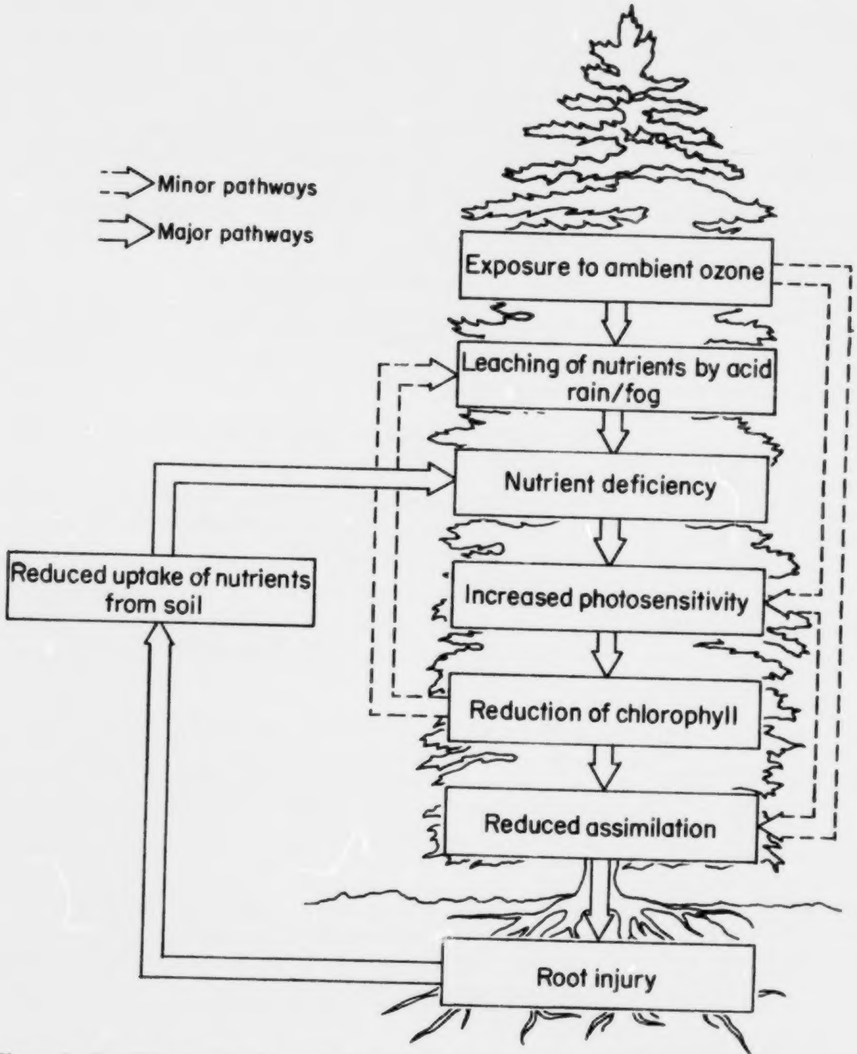
Minor pathways
Major pathways
Exposure to ambient ozone
Leaching of nutrients by acid rain/fog
Nutrient deficiency
Increased photosensitivity
Reduction of chlorophyll
Reduced assimilation
Root injury
Reduced uptake of nutrients from soil

Figure 5.--Possible impact of ozone and acidic fog or rain on conifer forests (Prinz et al. 1985).

In agreement with the second report of the Forschungsbeirat "Waldschaden/Luftverunreinigungen" (FBW 1986) the following assumption seems at the moment to be the most probable explanation of chlorosis of spruce. For other tree species other hypotheses may be more valid, including the influence on deciduous trees of "wet" summers after "dry" summers combined with the attack of parasites.

Causes for the temporal development:

- upward trend of ozone concentration during the last decades
- continuous loss of nutrients in soil by acidic deposition.

Causes for spatial distribution:

- increase of ozone concentration (as a daily average) with increasing altitude;
- geogenic differences in nutrient supply.

Cause for short term appearance (and recovery):

- climate as a triggering or synchronizing factor.

The crucial point in the chain of effects seems to be the impact of ozone on the cell membrane system, the loss of nutrients by leaching, the interaction of the soil and the root system with the impact of ozone on the above ground part of the tree (Figure 5.)

Evidence for this assumption includes:

- Reproduction of the light effect on nutrient deficient trees in the experiment.
- Enhanced leaching after ozone exposure, proven in experiments (Prinz et al. 1985) as well as in natural stands (Fabig et al. 1987). Significant increase of leaching if trees grow on poor soil and are already damaged, which was proven in experiments (Prinz et al. 1985) and in natural stands (Kaupenjohann et al. 1987).
- Effect of ozone on root system by way of nitrate accumulation (Krause, unpubl. data) as well as change in cytokinin and phenolic substances (Schwartzenberg and Hahn 1987, Strack 1987).
- The effect of aluminium on uptake of nutrients is also proven. On the other side no single relationship between intensity of damage and aluminium content in soil or needle exists, although this has to be expected in principal. The observation that in fertilizer experiments not calcium but magnesium provided the greatest initial effect on the recovery of trees suffering from chlorosis leads in the same direction. This means that chlorosis is not a simple reaction to soil pH but more a reaction to insufficient magnesium supply.

Evidence against this assumption includes:

- Episodes of forest decline have always existed. On the other hand, no episode in historical time developed in such a systematic way and was so widely distributed.
- The whole chain of effects has not yet been reproduced. This is especially true for the symptom of needle chlorosis. Here, one has to consider, however, that young trees used in experiments, are also "healthy" in nature, in contrast to the older trees. Furthermore, there is no doubt as the novel type of forest decline is a long lasting process with its own dynamics. In agreement with several other studies, spruce trees fumigated with ozone in experiements at the LIS (Krause and Höckel 1988) showed an initial increase in nutrients. But, nutrient levels decreased, compared to controls, after exposure for 1½ years in the Egge Mountains. It also has to be taken into consideration that ozone concentrations are well in the range of possible damage, apart from chlorosis of spruce, as shown experiments with Austrian Pine and beech (Prinz et al. 1985). Ozone-like damage was observed for the first time this autumn (1987) on white pine exposed in the Egge Mountains in eastern North Rhine Westphalia.
- Nutrient deficiency symptoms are quite normal and therefore without specific sign of decline even on extremely poor soils. This is only partly true since trees can adapt to quite different soil conditions when accustomed to this situation from very early youth.

Needs for further investigations

It is not possible to go into much detail here. The general concept of the research programme in the state of North Rhine-Westphalia (see Köth and Prinz, this proceedings) has the following three integrated stages:

- experiments in exposure chambers with controlled treatments with air pollutants,
- experiments in open top chambers within a damaged stand with application of natural and filtered air as well as with natural and "purified" rain,
- highly sophisticated observations with morphological, histological, physiological, biochemical and genetechnological methods in naturally exposed trees within a damaged and a control stand.

This concept has the following rationale. If only controlled experiments are executed, the question always remains open whether these results are comparable with natural conditions under quantitative as well as interactive aspects. So for example, the temporal pattern of concentration of air pollution in the field will never be replicated in a really realistic manner in the experiment. Also the more or less complex interaction with climate and soil can never be reproduced in full detail. On the other side, the observations in the natural stand very rarely provide conclusions about the factors causing damage with the exemption that the reactions observed in the plants of the natural stand are extremely specific.

The open top chambers are useful links within this integrated concept. If one gains the same principle results in all three stages than one can be fairly sure that the clue to the problem of forest decline has been found.

One has to confess that much valuable work has been done meanwhile on coniferous trees. Only a very limited section of the current state of knowledge could be given here. One of the main important questions still to be investigated is the influence of air pollutants, especially of ozone on the crown of the tree with secondary effects on the root system. At the same time the interactive effect between direct damage by air pollutants and soil conditions should be studied. On the whole, there is still an immense gap of knowledge with respect to deciduous trees. Future investigations will certainly focus especially on this aspect.

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Outline of Results from "Early Diagnosis of Forest Decline" Survey Carried Out in Europe in 1986

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Abstract

In 1986 a group of institutions carried out a survey of 14 sites spread across a transect of Europe from the Black Forest area of W. Germany to the North of Scotland. Samples gathered from Norway spruce, Scots pine and beech trees were subjected to an array of possible diagnostic indicators of forest decline. Some of these tests, especially with Norway spruce needle samples, showed a clear discrimination between sites. The data from the Scottish sites were often at one end of the range and the results from W. German sites at the other. These differences could be attributed to genotype, soil type, climate, etc. and are not necessarily pollutant induced. However, some of the tests were capable of making a discrimination based on injury when site effects were removed by logistic regression.

Over the past two decades, enhanced combustion of fossil fuels for power generation and transport has caused the emissions of oxides of nitrogen to increase whereas sulphur dioxide emissions have decreased slightly as the result of desulfurization and other control measures. As a result, tropospheric concentrations of ozone have also increased, particularly in rural areas. Predictably, these pollutants have been linked to the causes of recent forest decline in Central Europe but there is wide disagreement over which air pollutant (if any) is primarily responsible. Possible interactions between various atmospheric pollutants and other environmental stresses on plants further complicate the question. Analysis of tree ring growth patterns tend to indicate that this problem of forest decline started over 20 years ago. Intensive research activity has so far failed to isolate potential pathogens that could induce the phenomenon. Moreover, several different tree species from different genera are affected and it is very unusual for a particular pathogen to attack more than one genus.

National forest surveys based on visual appearance of trees have documented the extent to which different species in different areas of Europe have been affected, but, apart from the yellowing of needles associated with certain magnesium-deficient sites, a biochemical/physiological assessment of the numbers of affected and unaffected trees in forests, which can also be simulated by controlled fumigations with suspected atmospheric pollutants in the laboratory, has been lacking. In 1986, a survey of three species (Norway spruce, Scots pine and beech) at 14 sites across Europe from the Black Forest to North Scotland, known to have a wide range of pollution climates (Table 1), was undertaken (Cape et al. 1987, see also acknowledgments). Most of the samples collected were subjected to a wide range of 28 possible tests (Table 2) in the hope that such studies would provide nonvisual quantitative indicators of tree health and supply hints concerning the possible causes of forest decline.

Part of the survey team based at the Natural Environment Research Council Institute of Terrestrial Ecology (NERC-ITE) in Scotland was concerned with tests which provided information on changes of needle surfaces as well as with overseeing the analyses of major nutrients. Large site differences for Norway spruce (but not Scots pine) were shown in the amounts of surface waxes on present year (1986), previous year (1985) and 2-year-old needles (1984). All UK sites had smaller amounts of wax than continental sites. Similar differences were shown with the Hartel (1953) test but we believe that the response of this test to air pollution is more complex than thought hitherto. Large site differences were also shown by measurements of the contact angle formed with droplets of pure water were placed on sample needle surfaces. Consistently smaller values were found on older spruce needles gathered from UK and Dutch sites than those from W. German sites (Figure 1). Absolute values for Scots pine were less useful but the year-to-year changes showed a marked geographical pattern.

Changes in ultrastructure, gas exchanges, and modulated fluorescence were monitored by Dr S Fink, Freiburg University, Dr PH Freer-Smith, Ulster University (now UK Forestry Commission), and the Lancaster University group, respectively. All showed encouraging results which obviously require further development, but timing difficulties or the complexities of the techniques prevented their full participation in the whole survey. Lack of time also prevented the full use of measurements of levels of free radical scavengers such as α-tocopherol, glutathione and ascorbate by the Lancaster University group.

Initial measurements of pH of whole-needle homogenates and the titration of these were both acid or alkali to determine buffer capacities were also undertaken by the Lancaster University group. Large site differences were shown with determinations of leaf pH with less acidic values being shown by UK sites. However, buffering capacity of 2-year-old Norway spruce needles did not differ in any consistent way between sites. In current-year needles (1986), alkaline buffering (pH 8-10) was significantly reduced at W. German and Dutch sites but no significant site-related trend in acid buffering (pH 3-5) was apparent.

The same group also measured ethylene and ethane emission rates from small branches from each of the trees at the different sites as well as the levels of individual pigments in 2-year-old needles. Rates of ethylene emission from individually damaged Norway

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Table 1.--Summary of sampling site locations and their relative long term atmospheric pollutant climates (Cape et al. 1987)

Site code	Location	Number of trees sampled[a]	Pollution climate[b]		
			O_3	SO_2/NO_2	Acidity
	W. Germany				
D1	Kalbelescheuer (Black Forest)	12/-/8	+ + +	+	+ +
D2	Haldenhof (Black Forest)	8/4/6			
D3	Langebramke Sud (Harz)[c]	8/-/-	+ +	+	+ + +
D4	Langebramke Nord (Harz)[c]	8/-/-			
D7	Fichtelberg (E. Bavaria)	8/8/8	+ + +	+ + +	+ + +
D8	Selb (E. Bavaria)	8/8/8	+ + +	+ + +	+ + +
	Netherlands				
N1	Kootwijk (Gelderland)	6/6/6	+ +	+ +	+ + +
N2	Rips (Limburg)	6/6/6	+ +	+ + +	+ + +
	UK				
E1	Ashford (S.E. England)	8/8/8	+ +	+ +	+ +
E2	Winchester (S. England)	8/8/8	+ +	+ +	+ +
S1	Glenbranter (W. Scotland)	8/8/8	+	+	+ +
S2	Darnaway (N.E. Scotland)	8/8/8	+	+	+

[a] Norway spruce/Scots pine/beech.
[b] + = light; + + = medium; + + + = heavy.
[c] 8 Scots pine sampled at Celle (D5) and 8 beech at Witzenhausen (D6) nearby.

spruce and Scots pine trees varied greatly, but generally there were lower emissions from Norway spruce samples gathered at Scottish sites than those from the Netherlands or W. Germany (Figure 2). The emissions for Scots pine appeared to be related more to tree age. Analysis of pigments (both chlorophylls and carotenoids) by spectrophotometry and HPLC of pigment extracts from needles, frozen by immersion in liquid N_2 in the field, showed low violaxanthin to antheraxanthin ratios in 2-year-old Norway spruce needles and low violaxanthin to lutein ratios in Scots pine needles from UK sites when compared to analyses of those sample extracts from Dutch and W. German sites (Figure 3).

Stepwise discriminant analysis of all the results for 2-year-old Norway spruce needles indicated that 14 of the 42 variables measured by the survey team were capable of marking a significant ($>5\%$) contribution to the discrimination between sites (Table 3). When these were used in a simple average linkage cluster analysis, a clear discrimination between geographically adjacent sites was achieved (Figure 4). There was also a separation along a transect from Scotland to S. Germany with some similarities between sites in England, the Netherlands and the Harz region of W. Germany. If the 14 variables identified by stepwise discriminant analysis (Table 3) were used in a canonical discriminant analysis, then it was possible to rank the sites in terms of the first three canonical variables (Table 4). When these were related to the pollution climates (Table 1) of the sites then the first canonical variable was found to correlate significantly ($p<0.01$) with only mean rainfall pH and ozone, while the second

Table 2.--Diagnostic tests used in 1986 survey and collaborational responsibilities (asterisk indicates percent of dry weight).

1. Histological examination (Freiburg)

2. Water droplet contact angle measurements (NERC-ITE)

3. Hartel test (NERC-ITE)

4. Cuticular waxes (NERC-ITE)
    a. surface wax*
    b. insoluble surface material*

5. Needle composition (NERC-ITE)
    a. nitrogen*
    b. sulfur*
    c. calcium*
    d. magnesium*
    e. potassium*

6. Modulated leaf fluorescence (Lancaster)

7. Hydrocarbon emissions (Lancaster)
    a. ethylene
    b. ethane
    c. higher hydrocarbons

8. pH (Lancaster)
    a. initial leaf/needle homogenate pH
    b. acid buffer capacities
    c. alkaline buffer capacities

9. Pigment ratios (Lancaster)
    a. chlorophyll a to b
    b. total chlorophylls to carotenoids
    c. β-carotene to chlorophyll a
    d. β-carotene to xanthophylls
    e. violaxanthin to antheraxanthin
    f. violaxanthin to lutein

10. Levels of free radical scavengers (Lancaster)
    a. glutathione
    b. ascorbate
    c. α-tocopherol and metabolites

11. Physiological measurements (Ulster)
    a. shoot/water relations
    b. CO_2 exchange

12. Basic parameters and bases of expression (all)
    a. fresh weight
    b. dry weight
    c. various ratios based on a. and b. above
    d. visual injury classification on CEC system

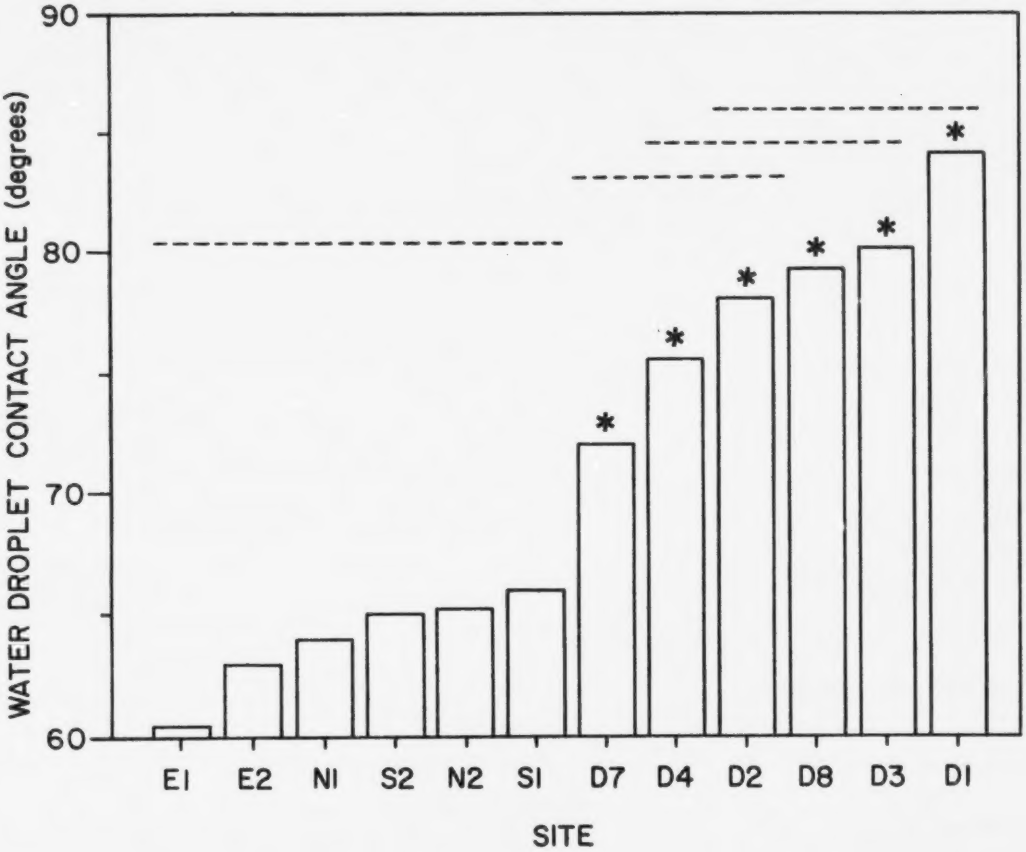

Figure 1.--Water droplet contact angles of 2-year-old Norway spruce needles gathered at different sites. Sites under the same horizontal bar are not significantly different from each other ($p > 0.05$) while an asterisk indicates sites differing significantly from site S2 ($P < 0.05$).

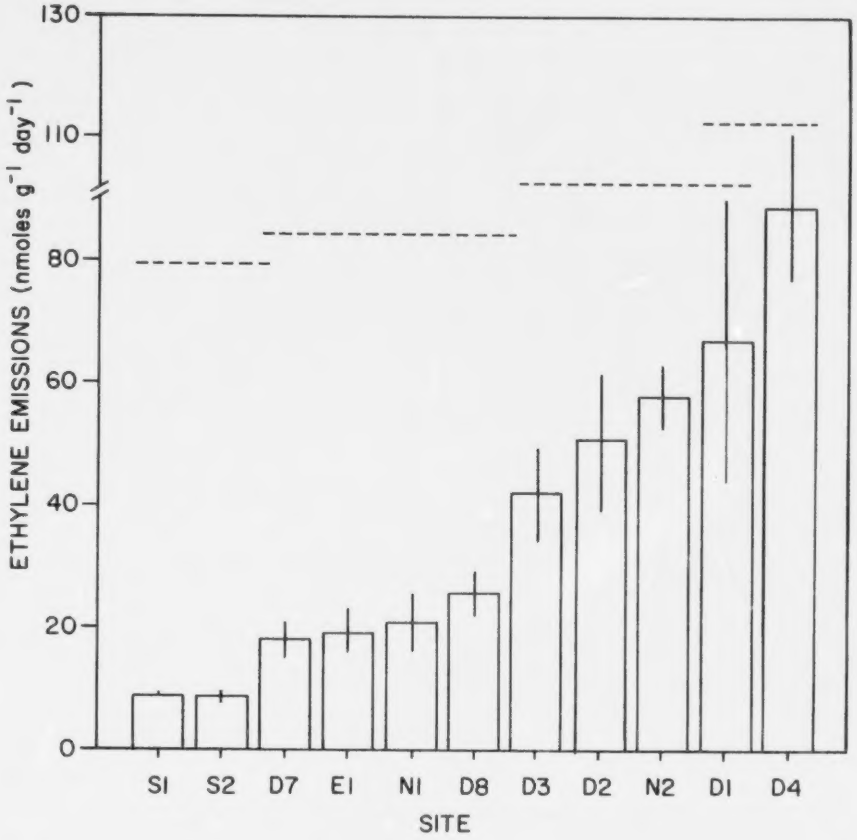

Figure 2.--Rates of ethylene emissions from Norway spruce needles gathered at different sites. Each result indicates the mean and standard error of at least 54 samples (3 replicates each from 3 needle ages of at least 6 trees) while sites under the same horizontal bar are not significantly different according to Duncan's multiple range test.

canonical variable correlated weakly ($p > 0.06$) with deposited acidity and the third ($p < 0.07$) with primary pollutant gases. The site ranking produced for the first canonical variable (Table 4) was very similar to the clustering produced by the average linkage method (Figure 4).

As will be observed in Figures 1-3, Duncan's Multiple Range Test was applied throughout most of the tests to identify similar sites and this is denoted by the dashed horizontal lines above the bars while asterisks are used to denote sites significantly different from S2 in Scotland. However, correlations between different tests have also been undertaken. Figure 5, for example, illustrates the strong correlation between rates of ethylene emissions from and the ratios of violaxanthin to antheraxanthin in 2-year-old Norway spruce needles at different sites. Equally interesting and significant relationships between these two tests and needle contact angles or dry weight differences between current and 2-year-old needles were found.

During this 1986 survey, wherever possible, samples of needles were taken equally from trees showing both damage or no obvious damage when the CEC standard classification of forest decline symptoms (Bauer 1984) were applied. Logistic regression analysis was applied to the respective classifications of trees from which samples were taken for tests with the intention of removing site effects. From such analyses three parameters were identified free from site effects from which it was possible to define the probability of tree injury. Moreover, these could be combined together to further strengthen the possibility of being able to use diagnostic indicators free from subjective visual classifications as a means of documenting the extent of forest decline in the field. These particular three parameters were the dry weight differences between present and 2-year-old needles, the rates of ethylene

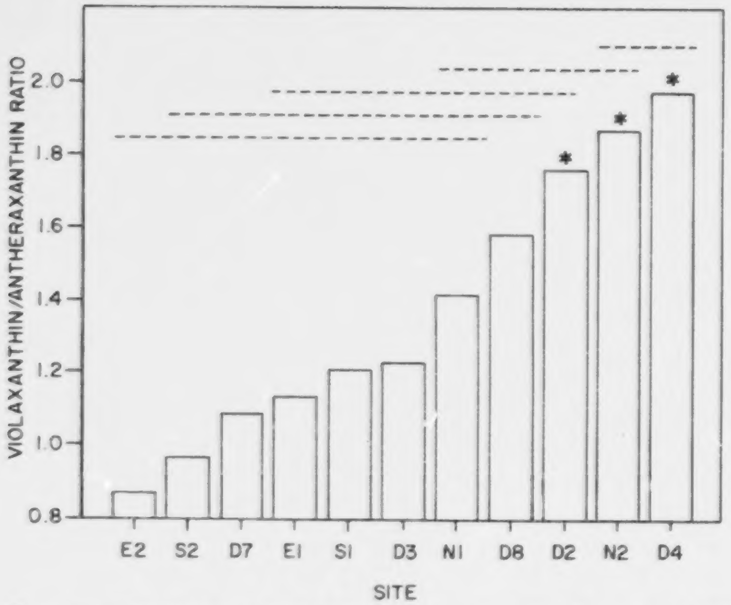

Figure 3.--Pigment ratios from 2-year-old Norway spruce needles gathered at different sites showing violaxanthin/antheraxanthin ratios. Sites under the same horizontal bar are not significantly different from each other ($P > 0.05$) while an asterisk indicates sites differing significantly from site S2 ($P < 0.05$).

Table 3.--Discriminant analysis for 2-year-old Norway spruce needles showing those variables making a significant (>5%) contribution

Variable	partial r^2	F-static	probability (F)
Needle content of calcium	0.79	20.9	0.0001
Needle content of sulphur	0.75	17.1	0.0001
Needle content of nitrogen	0.73	15.3	0.0001
Tissue homogerate pH	0.65	10.0	0.0001
Water droplet contact angle	0.62	8.8	0.0001
Needle content of magnesium	0.60	7.9	0.0001
Dust as percent of dry wt	0.55	6.5	0.0001
Violaxanthin:antheraxanthin	0.51	5.2	0.0001
Chlorophyll:xanthophyll	0.46	4.2	0.0002
Chlorophyll a:b	0.62	8.0	0.0001
Needle content of potassium	0 43	3.6	0.0007
Violaxanthin:lutein	0.41	3.3	0.0019
α-tocopherol	0.38	2.8	0.0062
Dry wt as percent of fresh wt	0.37	2.6	0.0094

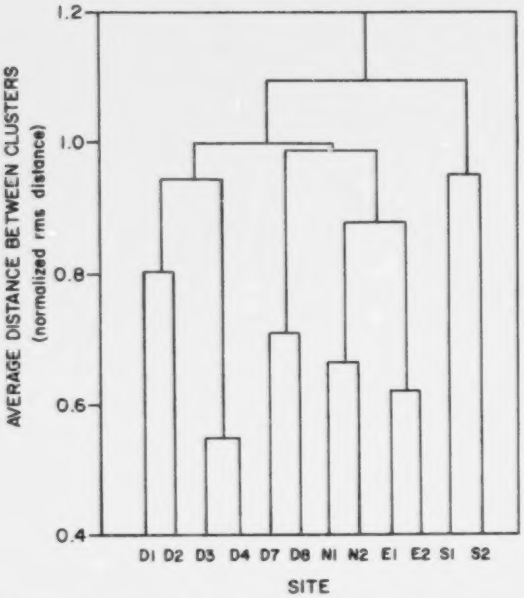

Figure 4.--Average linkage cluster analysis of sites using the 14 variable defined by the discriminant analysis (Table 3).

Table 4.--Site means for the first three canonical variables using 14 discriminant variables shown in Table 3 for 2-year-old needles of Norway spruce

Canonical variable					
1		2		3	
Site	Mean	Site	Mean	Site	Mean
S1	6.2	D8	4.1	N2	4.4
S2	4.2	D7	4.0	N1	2.5
E2	3.7	E1	1.1	S1	1.6
E1	2.8	S1	1.0	D1	1.4
D8	0.7	D3	-0.2	D8	1.2
N1	-0.9	D2	-0.5	E2	0.4
N2	-1.3	D4	-0.8	D7	-0.2
D3	-2.3	N1	-1.1	E1	-0.9
D2	-2.6	N2	-1.5	D4	-1.9
D1	-3.0	E2	-1.5	D2	-1.9
D4	-3.2	S2	-2.1	D3	-2.1
D7	-3.4	D1	-4.0	S2	-2.9

emission, and the ratios of violaxanthin to antheraxanthin. The results of a logistic regression analysis of an analysis combining all these three are shown in Figure 6.

Taken individually, these three tests would tend to imply that injury or decline is brought about by different factors. Growth (or lack of it) in the case of dry weight differences, general environmental stress of undefined cause by enhanced ethylene emissions, and photo-oxidant damage in the case of altered epoxidation of the two xanthophylls. When combined together they appear to cover the different components of forest decline and serve to emphasise how much more likely it is that the phenomenon is brought about by several interacting stresses--one of which is probably ozone.

One of the major benefits of the 1986 study was the very close collaboration in the field among the participating institutions especially NERC-ITE and Lancaster University. This meant that a very wide range of techniques could be applied to the same plant material and a much more complete picture has been gained than could have been obtained by the application of individual tests in isolation.

In order for any of these tests (or any other) to be of value as diagnostic tests, they must now be studied in greater detail under controlled conditions. The criteria for their successful development are:

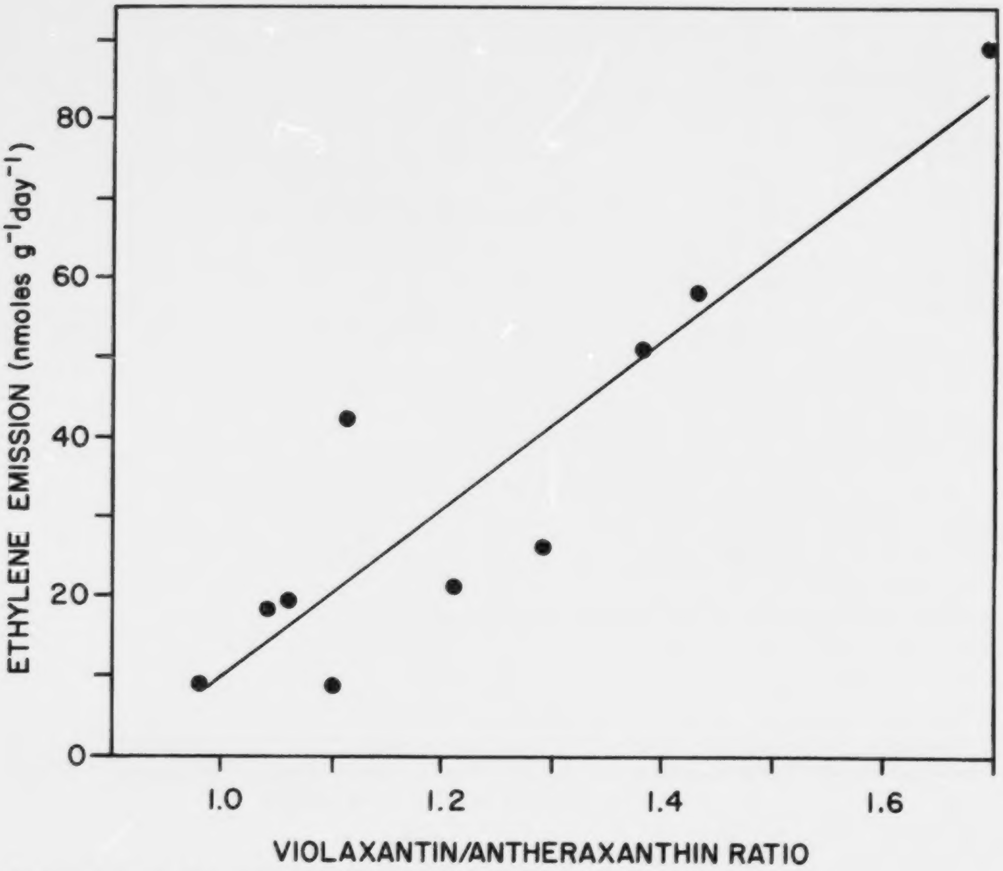

Figure 5.--Correlation of rates of ethylene emissions from Norway spruce needles collected at different sites to their respective mean ratios of violaxanthin to antheraxanthin. Each point is the mean of at least 6 trees and the slope of the fitted line: r is 0.873 ($P<0.01$).

(a) Small variation between genotypes,

(b) Small (or controllable) variation with conditions (e.g. weather),

(c) Small (or predictable) variation with leaf/needle age,

(d) Small (or predictable) variation with tree age,

(e) Specific response to individual pollutants.

In addition, the influences of other stresses (e.g., frost, drought or nutrient deficiency) should be recognized, although these may interact with pollutant stresses.

Plans are already well advanced to grow young trees and rooted older shoots in controlled environments for use in further development. Ultimately, the refined tests will need to be reexamined by more extensive surveys in the field which we hope will take place in 1990 or 1991, but funding for this is still required. However, we marked each of the trees from which samples were taken at the different forest sites and it would be very interesting to gain further results in 1990 or 1991 from the same trees as used in 1986.

Acknowledgments

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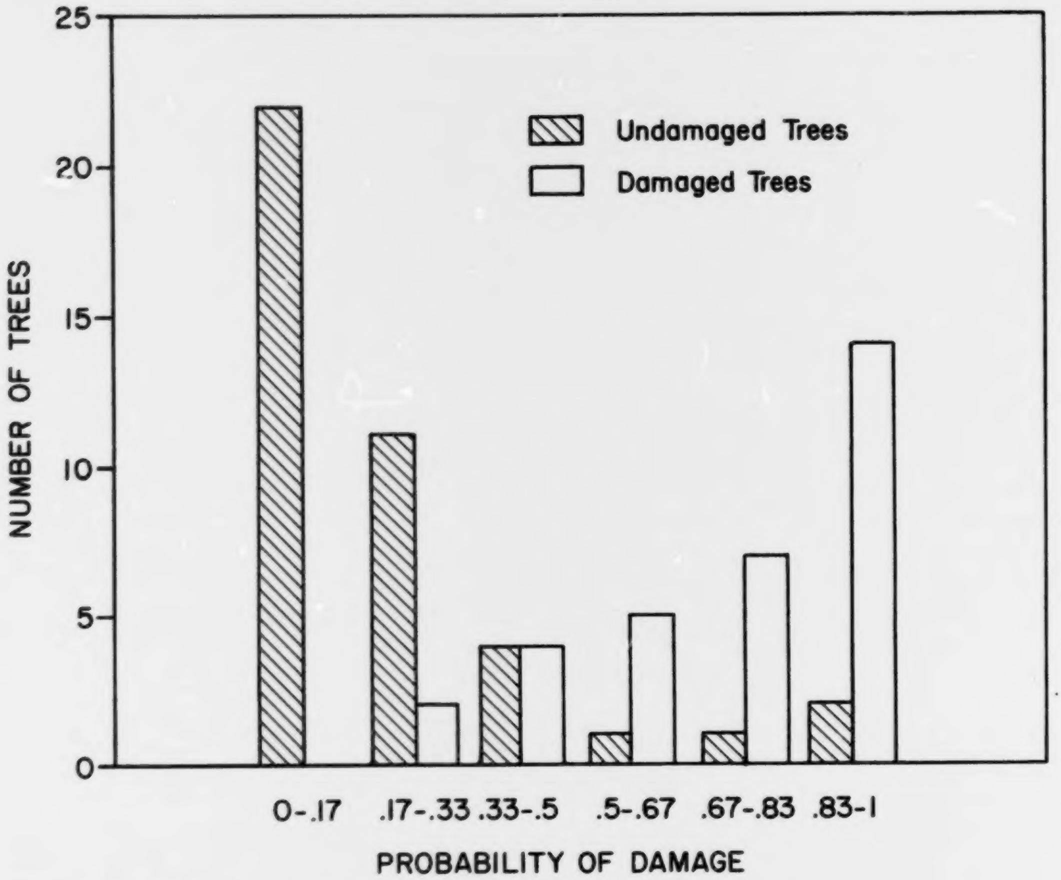

Figure 6.--Numbers of Norway spruce trees that fitted into classes of probability of injury calculated by multiple logistic regression analysis of the logarithms of the dry weight differences from present year to 2-year-old needles plus the violaxanthin to antheraxanthin ratios from 2-year-old needles as well as their emissions of ethylene. The overall value of p was less than 0.01.

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Evaluation of Tree Mortality in the Spruce-Fir Forest of the Southeastern United States

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Abstract

An aerial photographic and ground evaluation was made by the USDA Forest Service in the spruce (***Picea rubens*** *Sarg.) and Fraser fir* (***Abies fraseri*** *[Pursh] Poir) type during 1985. The purpose of the evaluation was to delineate on maps the entire spurce-fir type and to classify and map tree mortality and/or decline. This information, which was entered into a geographical information system, and the 100 percent aerial photographic coverage will serve as baseline data for determining future trends on the status of spruce-fir in the Southeast. Results of the evaluation showed 65,752 acres (26,609 hectares) of spruce-fir in the southern Appalachians. Overall tree mortality was 8 percent for red spruce and 67 percent for Fraser fir.*

Introduction

Concern about mortality in the spruce-fir forest of the southeastern United States indicated an immediate need to conduct a survey to map the extent and severity of the damage. The forest type is comprised of red spruce (*Picea rubens* Sarg.), which occurs from North Carolina to Nova Scotia, and Fraser fir (*Abies fraseri* [Pursh] Poir.), which occurs only in North Carolina, Tennessee, and Virginia.

Because of the geography and topography of the region, spruce-fir forests in the South occur as a series of island-like stands at high elevations. The southern Appalachian spruce-fir is believed to be threatened by an exotic insect pest, the balsam woolly adelgid (*Adelges piceae* Ratz.), by atmospheric deposition of pollutants, and possibly by other agents. This forest type represents an extremely valuable resource in the South because of its unique natural beauty, its importance for recreation, and its importance as a seed source for Christmas trees and nursery industry. It is considered by many to be a threatened species type because of its marked decline in area.

In addition to the threat of the balsam woolly adelgid, the spruce-fir type may be particularly vulnerable to atmospheric deposition of pollutants. These high-elevation forest types probably receive more deposition because of the higher precipitation and cloud immersion than lower elevations. The complicated nature of the spruce-fir forest mortality and the difficulty in establishing a cause and effect relationship indicated a more pressing need for establishing baseline data on the current status of the spruce-fir type and its relationship to previously recorded geographic information which may be analyzed through the utilization of a geographic information system (GIS).

Objectives

1. Locate and delineate on maps all red spruce and Fraser fir in the southern Appalachians.
2. Classify all red spruce and Fraser fir mortality (percent of dead standing trees) visible on aerial photographic coverage in the states of Tennessee, North Carolina, and Virginia.
3. Using a combination of aerial photographic sampling and ground checks, estimate losses within the spruce-fir type.
4. Acquire large scale aerial photography of previously established research plots.
5. Develop and implement a geographic data base on the extent and intensity of mortality in the spruce-fir type in North Carolina, Tennessee, and Virginia.
6. Provide for comparisons between the extent and intensity of mortality in relation to other geographic information through the computer analysis, storage, and display of spacial (geographic) information.

Methods

Aerial Photographic Acquisition

Color infrared aerial photography at a scale of 1:12,000 of the entire spruce-fir type was acquired in stereo during the summer (leaf-on season) of 1984. An Aero Commander 680-F, equipped with an RC-10 camera and a geographic coordinate referenced navigation system, was used to acquire the photography. In the winter of 1985, true color positive transparencies were acquired in stereo during the leaf-off season over the entire spruce-fir range at a scale of 1:12,000. This photography was used to modify the previously identified boundaries and mortality strata for more specific and detailed evaluations. Underflights were made of previously established research plots at a scale of 1:4,000. All photography was indexed on USGS 1:24,000 scale topo sheets, and the photography and maps were available to other investigators.

Photo Interpretation

Boundaries of the spruce-fir were delineated by skilled aerial photographic interpreters directly on the aerial photographic transparencies using Bausch and Lomb 240 zoom stereoscopes mounted on MIM 4 Richards light tables. For this project, the spruce-fir type was defined as any area where spruce or fir was discernible on the aerial photographs. The boundaries of the type and mortality classes were then transferred to 1:24,000-scale USGS topo maps. Within the spruce-fir type, the following

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categories of mortality were recognized: (1) light to moderate--less than 30 percent of the standing dominant and codominant trees dead, (2) heavy--30 to 70 percent standing dominant and codominant trees, and (3) severe--more than 70 percent of the standing dominant and codominant trees dead.

Stratification and Selection of Sample Plots

During the photo interpretation, individual areas were sampled within the three mortality classes. Each mortality class was randomly sampled in proportion to the area of spruce-fir type affected. Two hundred and thirty-two 1/5-acre plots were selected on Mt. Mitchell, Roan Mountain, Blue Ridge Parkway, and Great Smoky Mountains National Park. Randomly selected 1/5-acre plots were viewed in stereo to determine the number of dead spruce and fir trees, and the total number of spruce and fir trees visible in the plots.

Ground Survey

A total of 132 of the 1/5-acre photo plots was randomly selected as plots for the ground phase of the evaluation. Ground crews located the center of the photo plots on the ground and marked them with a metal stake. General information, such as slope, aspect, and the presence of balsam woolly adelgid, was collected. Starting at the center of the plot, a cluster of five sampling plots were established, with the center stake serving as the first point and the other four systematically arranged in a procedure similar to that used by the Southeastern Forest Experiment Station, Forest Inventory and Analysis work unit, as described in their field instruction book. Data were taken at each point in a variable size plot established by a prism with a basal-area factor of 37.5. A fixed-radius plot of 6.8 feet was also established at each point in the cluster. There were two sets of data taken at each point in the cluster on two separate data sheets. The following data were taken on each tree for the variable size sampling points: (1) species, (2) d.b.h. (5 inches or greater), (3) condition, (4) total height, (5) crown position, and (6) destructive agents. On the 6.8-foot radius plots, the following data were taken on each tree 1 inch d.b.h. or greater: (1) species, (2) d.b.h., (3) condition, (4) destructive agents, and (5) crown position.

Map Digitizing and Data Entry

Maps were reviewed before data entry to verify proper attribute placement and polygon closure, as well as edge mapping adjacent quad sheets. The boundaries of the spruce-fir type, with the interior areas classified by mortality, were digitized from 27 quad sheets. The MOSS family of software was used as the GIS for data entry, analysis, and display of the data. The GIS is a set of software for encoding, transformatting, analyzing, and displaying map and other geographic-based information. The system includes three components: (1) the Analytical Mapping System (AMS) for digital data entry; (2) Map Overlay and Statistical System (MOSS) and Map Analysis and Processing Systems (MAPS) for data processing, analysis, and display; and (3) Cartographic Output System (COS) for plotting and producing maps. This software was installed on a MV 4000 Data General minicomputer with over 800 megabytes on line disk storage capacity along with a high-density tape drive. The system also includes two large-format digitizing stations with graphic terminals, color graphic display stations, image display station, and text terminals. An eight-pen plotter provides map output products.

Primary data themes, i.e., those data layers which would be found for all topo maps containing spruce-fir type, were created as follows: (1) spruce-fir type boundaries, (2) spruce-fir mortality classification, (3) topography, (4) transportation, (5) ownership, and (6) drainage. Secondary data themes which included information over portions of the spruce-fir type were: (1) study plot locations, (2) photo index, (3) disturbance history, (4) balsam woolly adelgid protection boundaries, (5) balsam woolly adelgid mortality history, (6) balds, (7) spruce-fir forest type (with hardwood component) for the Great Smoky Mountains National Park, (8) railroad right-of-ways for previous logging activities, (9) 1960 mortality map for Mt. Mitchell, and (10) other data themes as they become available.

Results and Discussion

Data were analyzed by region of spruce-fir type in the Southeast as follows: (1) Great Smoky Mountains National Park, (2) Blue Ridge Parkway, (3) Roan Mountain, (4) Grandfather Mountain, (5) Mt. Rogers/White Top Mountain, and (6) Mt. Mitchell. Data were also compiled to summarize conditions throughout the Southeast. At this time, distribution of the spruce-fir and mortality in relation to elevation has been the primary focus of investigations.

Maps displaying the distribution and stratification of mortality in relation to all primary data themes were produced with legends indicating the total number of acres of spruce-fir type classified by mortality. An analysis of the data for spruce-fir mortality by region will include the following GIS analysis: (1) mortality classification expressed in number of acres and percent of area by geographic region (Table 1), and (2) acres of mortality stratified by elevation expressed as a percent of total area by region (Table 2). Spruce-fir mortality data analysis, based solely on ground truth, will include: (1) percent of spruce and fir mortality classified by elevation for each region (Table 3), and (2) percent of the stand component for spruce and fir classified by elevation for each region (Table 4).

At this point, severe mortality appears to occupy a greater proportion of the area at higher elevations as opposed to lower elevations. These higher elevation stands also contain a much greater percentage of Fraser fir. Fraser fir mortality, as observed in this study, is very consistent with reports of published balsam woolly adelgid activity. A very strong agreement between ground sample points and aerial sample points was found, indicating that future surveys could rely on photography with only a minimum of ground surveys.

Table 1.--Spruce-fir forest in the Southeast, classified by mortality

Geographic area	Light mortality No. acres	Light mortality %	Heavy mortality No. acres	Heavy mortality %	Severe mortality No. acres	Severe mortality %	Total No. acres
Great Smoky Mountains National Park	35,759	73	2,692	6	10,365	21	48,816
Mt. Mitchell	5,409	75	289	4	1,514	21	7,212
Roan Mountain	256	17	583	38	698	45	1,537
Mt. Rogers/White Top Mountain	1,582	100	0	0	0	0	1,582
Grandfather Mountain	659	71	124	13	145	16	928
Blue Ridge Parkway	2,058	37	550	10	2,989	53	5,597
Total	45,723	70	4,238	6	15,711	24	65,672

Table 2.--Spruce-fir mortality in the Southeast, stratified by elevation

L = light mortality; H = heavy; S = severe

	Mortality (% of Area)											
	4600 ft			4600-5200 ft			5200-5800 ft			5800-6400 ft		
Geographic area	L	H	S	L	H	S	L	H	S	L	H	S
Greak Smoky Mountains National Park	7	0	0	39	2	0	26	3	15	1	1	5
Mt. Mitchell	4	0	0	22	0	0	29	1	2	19	3	16
Blue Ridge Parkway	1	0	0	6	1	1	26	8	34	5	1	18
Roan Mountain	0	0	0	1	1	0	10	16	24	5	22	21
Grandfather Mountain	7	0	0	28	1	1	35	12	12	1	0	1
Mt. Rogers/White Top Mountain	2	0	0	54	0	0	44	0	0		NA	
Spruce-Fir Type in the Southeast	7	0	0	34	1	1	25	3	13	4	2	9

It should be noted that this survey was a one point in time analysis of mortality within the spruce-fir type and certainly not a measure of mortality over a period of time. Also, it is a measure of mortality of trees 5 inches or greater and does not include reproduction. It is known that a spruce or fir tree may stand for up to 20 years and still may be visible on aerial photographs. Further investigations will be necessary to develop a stronger cause and effect relationship to account for mortality observed during this survey.

In general, the spruce-fir type in the Southeast occupies 65,752 acres. Seventy-four percent of this forest type was found to occur on the Great Smoky Mountains National Park, followed by Mt. Mitchell at 11 percent, Blue Ridge Parkway at 10 percent, Roan Mountain at 2 percent, Mt. Rogers/White Top at 2 percent, and Grandfather Mountain at 1 percent.

Within the spruce-fir type, 70 percent of the total area was classified as light to moderate mortality (less than 30 percent standing dead trees); heavy mortality occupied 6 percent of the total area (30 to 70 percent dead), and 24 percent of the total area was classified as severe mortality (more than 70 percent dead). Overall tree mortality for the entire type was 8 percent for red spruce and 67 percent for Fraser fir.

Table 3.--Results of ground truth for spruce-fir mortality, by elevation stratum

N = number of trees sampled

	4200-5400 ft				5400-6000 ft				6000-6500 ft				Overall	
	Spruce		Fir		Spruce		Fir		Spruce		Fir		Spruce	
Geographic area	N	%[a]	N	%	N	%	N	%	N	%	N	%	N	%
Mt. Mitchell	102	10	4	100	83	13	57	23	18	39	54	72	203	14
Roan Mountain	17	6	27	67	83	1	181	50	16	13	129	30	116	3
Blue Ridge Parkway	12	0[b]	14	0[b]	128	5	160	93	5	0[b]	3	0[b]	145	5
Great Smoky Mountains National Park	105	13	44	100	147	6	120	88	25	4	14	86	277	9

[a] Percent of sample trees dead.

[b] Insufficient sample size.

Table 4.--Spruce-fir forest type stand component in percent, by elevation stratum for ground samples
(S = red spruce; F = Fraser fir)

	4200-5400 ft			5400-6000 ft			6000-6500 ft			Overall	
Geographic area	S	F	Other	S	F	Other	S	F	Other	S	F
Mt. Mitchell	58	2	40	35	24	41	22	66	12	41	2
Roan Mountain	19	31	50	27	59	14	11	87	2	21	6
Blue Ridge Parkway	21	24	55[a]	33	42	25	63	38	0	32	3
Great Smoky Mountains National Park	52	22	26	43	36	21	64	36	0	48	

[a] Insufficient sample size.

Throughfall and Stemflow Measurements at Mt. Mitchell, NC, During the Summer of 1986: A Preliminary Report

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Introduction

The major objective of the Mountain Cloud Chemistry Program is to characterize the exposure of montane forested ecosystems in the eastern United States to different types of chemical, physical and climatic atmospheric inputs. Such data is required by researchers in the Eastern Spruce-Fir Research Cooperative who are attempting to determine the possible role of acidic deposition (specifically acidic N and S compounds) on the observed high-elevation forest decline. Emphasis is placed on cloud water chemistry because of the greater acidity of cloud water as opposed to rain water, and enhanced cloud droplet deposition on needle surfaces due to cloud interception within the forest canopy.

Meeting the objectives of the Mountain Cloud Chemistry Program requires a combined effort utilizing actual field measurements and computer modeling of the physical and chemical processes occurring both outside and inside the forest canopy. Presented in this report is a preliminary summary of our field measurements of throughfall and stemflow at Mt. Mitchell, NC, for the summer of 1986. The report will focus on the ionic composition of throughfall and stemflow samples collected, and the estimates of H, NH4, NO3, and SO4 deposition that can be derived from these measurements. The limitations of such estimates are then addressed, especially in regards to the fact that 1986 was essentially a drought year in the Southeastern United States.

Methods and Materials

Site Location

Field collection of samples was performed at two sites during the summer of 1986. Site 1 was located on Mt. Gibbes, NC (2006 m), which is located approximately 2 km due south of Mt. Mitchell, NC. Site 2 was located on the east face of Commissary Ridge (1760 m), which is due east of Mt. Mitchell. A fully instrumented meteorological tower was installed at each site as well as the necessary laboratory and living facilities.

Sample Collection and Field Analysis

Cloud water. Cloud water samples were collected hourly on an event basis using an ASRC teflon-string passive collector and 500-ml polyethylene bottles. Total volume collected, sample conductivity, and pH were measured immediately after each sample was collected. Subsamples were set aside for chemical analysis and maintained at 4°C until shipment to the laboratory. Separate rain events were not sampled, but rain during certain cloud events was collected as part of the cloud water samples. Such occurrences were duly noted. The ASRC collector was kept covered with a plastic bag between cloud events to prevent contamination by dry deposition.

Throughfall and stemflow. Throughfall collectors consisted of a 27-cm-diameter polyethylene funnel placed 1 m above the forest floor approximately 1 m away from the bole of a tree. Cheesecloth was placed at the bottom of each Tygon collection tube leading from each funnel as a filter to prevent foreign matter from mixing with the sample in the 2-liter brown polyethylene collection bottle.

Nine collectors were established at each site but differences in forest canopy prevented replication of collector placement. Four collectors were placed under 2 Fraser fir trees, and 2 collectors were positioned under 1 red spruce tree at Site 1. Three collectors were placed in open areas within the canopy. At Site 2, the collectors were placed randomly under a canopy of even-aged red spruce and Norway spruce. No open collectors were placed at Site 2.

Stemflow collectors consisted of 1-inch-diameter Tygon tubing split in half and wrapped at a slant around the bole of a tree. The tubing was secured to the tree with aluminum nails and sealed to the bark with silicon caulking. This design was very efficient at catching high flow rates down the bole of a tree and sample loss during such events was minimal. Cheesecloth was placed at the bottom of each Tygon collection tube leading from each funnel as a filter to prevent foreign matter from mixing with the sample in the 2-liter brown polyethylene collection bottle.

Six stemflow collectors were installed at site 2, and Site 1 (4 collectors on Fraser fir trees and 2 collectors on red spruce trees).

Samples were collected on an event basis. Throughfall collectors were kept covered with plastic bags between events to prevent contamination by dry deposition. Once an event started the plastic bags were removed and the collectors left uncovered until the event was over. Approximately 30 minutes after an event, the collection bottle was removed and replaced with another. Total volume and sample pH were measured within 30 minutes after each sample was collected. Subsambles were set aside for chemical analysis and maintained at 4°C until shipment to the laboratory. Both throughfall and stemflow collectors were rinsed with deionized water at least once a week, or after an event if the amount of foreign material (insects, needles) falling into the collectors was substantial. Throughfall and stemflow samples were collected after both cloud and rain events.

Chemical Analysis

Cloud water, throughfall, and stemflow samples were analyzed for soluble Cl, NO3, and SO4 by suppressed ion chromatography, total dissolved Ca, Mg, K, and Na by atomic absorption spectroscopy, and soluble NH4 by colorimetry using phenol-based reaction. Laboratory and field pH measurements usually agreed to within 0.05 pH units.

Quality Assurance/Quality Control

Field and laboratory measurements were carried out using written protocols provided by the Mountain Cloud Chemistry Program. Internal and external audits were conducted during the sampling period at each field location and at the laboratory. Chemical analysis was monitored using external quality control samples and by submitting separate cloud water samples to a central analytical laboratory. Further information and copies of documentation can be obtained by contacting Ann Mounteer, W.S. Fleming Associates, Albany, NY.

Results and Discussion

Ionic Composition

Most of the stemflow and all of the throughfall samples collected in 1986 were the result of rainfall events. Cloud interception, especially by low moisture content orographic clouds, was insufficient to produce enough sample for chemical analysis using our collection technique. Thus the sample collected represents an integration of the deposition from rain plus the deposition from cloud events that occurred prior to the rain event. The rain event itself may have occurred as a separate storm or during a cloud event. Estimates of deposition from rain events were obtained from the open collectors at Site 1.

The ionic composition of cloud water, rain water, throughfall, and stemflow samples collected in 1986 is shown in Tables 1 and 2. Mean volume-weighted concentrations are used to account for the differences in volume collected between events and between the different collectors. Cloud water is an order of magnitude more acidic than rain water (open collector), with NH4, NO3, SO4, and H as the dominant ions in solution. These four ions also dominant the chemistry of rain water, with the difference in concentrations being due primarily to the difference in moisture content between cloud droplets and rain drops. The dominant cation is H, with NH4 making up only about 30 percent of the positive charge in cloud water. However, NH4 does comprise over 50 percent of the inogranic-N in both cloud water and rain water.

Throughfall and stemflow are more acidic than rain water, but less acidic than cloud water. This trend holds true for both Site 1 and Site 2. Stemflow is more acidic than throughfall, probably due to the presence of dissolved organic acids. Stemflow samples were typically highly colored, while throughfall samples were almost always clear. However, the effective collection surface for the stemflow samplers is greater than the throughfall collectors such that the difference in acidity may reflect a significant input from cloud water during the rain event that generated the sample.

Besides acidity, the concentration of the remaining anions and cations is higher in throughfall and stemflow samples than in rain water, but less than or equal to the corresponding concentrations in cloud water. There is also a shift in the dominant cations with H and especially NH4 being replaced by K, Ca, and Mg. Evaporation from needle surfaces during a rain event will increase the concentration of ions in solution, but probably not to the extent required by the data in Tables 1 and 2. The increase in concentration for Cl, Na, K, Ca, and Mg is probably a result of leaching from the needles. Nutrient cycling of K is normal and well documented in the literature. Release of Cl, Na, Ca, and Mg is also known but to a lesser degree.

Release of NO3 and SO4 from the needles in amounts needed to increase the concentration of these ions to the extent demonstrated in Table 1 is highly unlikely. It is more probable that the increase in concentration observed for these ions is due to prior deposition from cloud events of low moisture content and dry deposition. Partial neutralization or absorption of the acidic deposition accounts for the decrease in the concentration of H and NH4 in the throughfall and stemflow. Assuming that NO3 and SO4 are absorbed to a lesser degree or not at all requires the release of other cations to maintain the charge balance. Thus the increase in concentration of K and especially Ca and Mg is most probably a direct response to acidic deposition. The extent to which this reaction occurs is not evident from the data in Tables 1 and 2 because of the limitations of comparing concentration data between different collectors and different trees. A more appropriate approach is to calculate percentages of the total ion pool for each collector type in Tables 1 and 2.

The percentages of the total ion pool for each collector type in Tables 1 and 2 are listed in Table 3. There appears to be no change in the relative importance of the anion composition as either cloud or rain water passes through the canopy. This apparently holds true for both throughfall and stemflow and between tree species at Site 1. The change for red spruce at Site 2 may be due to the presence of organic acids and will be discussed in more detail.

The change in the relative importance of the cation composition, as suggested from Tables 1 and 2, is consistent for throughfall and stemflow at both Sites 1 and 2. The largest decrease is for H, approximately 10 percent of the total ion pool, followed by a change of 7 to 10 percent in NH4. This change is reflected in the increase in the percentage of base cations, especially K and Ca, both of which increase by approximately 10 percent. There is an increase in the percentage of Mg in throughfall and stemflow but much less than that for Ca. As expected, the percentage for the total ion pool for Na remains essentially constant.

Ideally, the anion and cation percentages of the total ion pool in Table 3 should equal 50 percent. The positive bias in the percentage for the cations is probably due to analytical variance and using the mean volume-weighted concentration data in Table 1 and 2 to calculate the results in Table 3. The positive bias in the percentage for cations for the collectors at Site 2, however, is much greater than among the other collectors and is accompanied by a decrease in the percentage for SO4. These collectors also have the largest percentage increase for the base

Table 1.--Mean volume-weighted concentration per event of H, Cl, NO3, and SO4 for cloud water, rain water, throughfall, and stemflow samples collected in 1986 at Mt. Mitchell

Collector	pH	H	Cl	NO3	SO4
			µmol/l		
Cloud[a]	3.30	496	28	212	318
Rain[a]	4.21	62	5	18	35
Red spruce					
Site 1[b]					
Throughfall	3.90	127	21	54	120
Stemflow	3.71	193	35	80	168
Site 2[c]					
Throughfall	3.91	124	45	79	110
Stemflow	3.64	227	100	137	268
Fraser fir					
Site 1					
Throughfall	4.00	101	18	47	114
Stemflow	3.65	226	34	88	198

[a] Collected at Site 1.

[b] Mt. Gibbes, NC (2,006 m); June 29, 1986-Sept. 21, 1986.

[c] East face of Commissary Ridge (1,760 m); June 29, 1986-August 15, 1986.

Table 2.--Mean volume-weighted concentration per event of NH4, Na, K, Ca, and Mg for cloud water, rain water, throughfall, and stemflow samples collected in 1986 at Mt. Mitchell

Collector	NH4	Na	K	Ca	Ng
			µmol/l		
Cloud[a]	241	55	8	48	27
Rain[a]	26	4	7	5	1
Red spruce					
Site 1					
Throughfall	23	12	63	44	15
Stemflow	41	18	88	60	18
Site 2					
Throughfall	32	29	87	75	23
Stemflow	56	39	161	219	58
Fraser fir					
Site 1					
Throughfall	37	11	63	37	14
Stemflow	53	22	75	61	18

[a] Collected at Site 1.

cations, especially Ca. Most of the samples collected at Site 2 were colored, indicating the presence of organic matter. This is especially true for the stemflow samples which often tended to be light to dark brown in color and cloudy in appearance. The canopy selected at Site 2 for sample collection in 1986 is a fairly uniform, even-aged stand of 15-20 m red spruce and Norway spruce trees. The canopy at Site 1 is less intact, with smaller trees having different crown structure than the trees at Site 2. Thus, part of the reason for the differences observed between the two sites may be due to differences in the total surface available for interaction with cloud and rain water. However, it is also possible that the differences between sites could reflect differences in foliar and soil nutrient status.

Deposition Estimates

Estimates of total deposition via rainfall and throughfall are listed in Tables 4 and 5. The estimates for Site 2 have been normalized to the same collection period as Site 1. Except for H and NH4, deposition within the forest canopy via throughfall is substantially greater than via rainfall, and of the same order of magnitude between sites and between tree species. Direct measurement of deposition via cloud water interception is not possible using our collector and sampling design, but an estimate of the amount of deposition via cloud water interception can be obtained by correcting the deposition calculated from throughfall for the contribution from rainfall. This correction, listed under the subheading of "Excess" in Tables 4 and 5, yields estimates of 50 to 60 percent of the SO4, and 40 to 60 percent of the NO3 reaching the forest floor as being due to cloud water deposition or dry deposition. Given the high frequency of cloud occurrence in this ecosystem, the chief source of this NO3 and SO4 is probably deposition via cloud water interception on the canopy needle surfaces.

Estimates of the deposition of H and NH4 via cloud water interception using this approach yield essentially zero or negative values (Tables 4 and 5). This is consistent with the data in Table 3 and supports the assumption that the forest canopy serves to neutralize deposited H from cloud water, and absorbs the accompanying NH4. The rate of absorption of NH4 is apparently such as to remove a significant fraction even during the rain events.

Table 3.--Percentage of total ions (expressed in μeq/1) per event for cloud water, rain water, throughfall, and stemflow samples collected in 1986 at Mt. Mitchell (Thru = throughfall, Stem = stemflow)

			Red Spruce				Fraser Fir	
			Site 1		Site 2		Site 1	
Ion	Cloud water	Rain water	Thru	Stem	Thru	Stem	Thru	Stem
Anions	47.9	45.6	47.9	47.6	42.3	42.7	48.3	49.2
Cl	1.5	2.5	3.2	3.7	5.5	5.5	3.0	3.2
NO3	11.6	8.8	8.2	8.4	9.7	7.6	7.7	8.4
SO4	34.8	34.3	36.5	35.5	27.0	29.6	37.6	37.6
Cations	52.1	54.4	52.1	52.4	57.6	57.3	51.7	50.8
H	27.2	30.4	19.3	20.4	15.3	12.5	16.6	21.5
NH4	13.2	12.7	3.5	4.3	3.9	3.1	6.1	5.0
Base Cations								
NA	3.0	2.0	1.8	1.9	3.6	2.2	1.8	2.1
K	1.0	3.4	9.6	9.3	10.7	8.9	10.3	7.1
Ca	5.2	4.9	13.4	12.7	18.5	24.2	12.2	11.6
Mg	3.1	1.0	4.6	3.8	5.7	6.4	4.6	3.4
Sum	12.3	11.3	29.4	27.7	38.5	41.7	28.9	24.2

Table 4.--Total deposition of H, Cl, NO3, and SO4 from rain or throughfall, June 29, 1986 to Sept. 21, 1986, Mt. Mitchell

Collector	H	Cl	NO3	SO4
	kg/ha			
Rain	.14	.35	2.40	7.3
Red spruce				
Site 1	.24	1.42	6.26	21.6
Site 2	.18	2.24	6.91	14.9
Fraser fir				
Site 1	.15	.87	3.87	15.7
		Excess*		
Red spruce				
Site 1	.10	1.07	3.86	14.3
Site 2	.04	1.89	4.51	7.6
Fraser fir				
Site 1	.01	.52	1.47	8.4

*Throughfall minus rain.

Table 5.--Total deposition of NH4, Na, K, Ca, and Mg from rain or throughfall, June 29, 1986 to Sept. 21, 1986, Mt. Mitchell.

Collector	NH4	Na	K	Ca	Mg
	kg/ha				
Rain	1.04	.20	.54	.46	.07
Red spruce					
Site 1	.80	.52	4.65	3.35	.67
Site 2	.82	.93	4.72	4.26	.77
Fraser fir					
Site 1	.93	.34	3.46	2.02	.46
Red spruce					
Site 1	-.24	.32	4.08	2.90	.60
Site 2	-.22	.73	4.18	3.80	.70
Fraser fir					
Site 1	-.11	.14	2.89	1.56	.39

An estimate of H and NH4 deposition via cloud water interception is possible assuming that (1) an ammonium sulfate compound is the principle source of NH4 in cloud water, and (2) that SO4 deposited from cloud water interception is not absorbed by the forest canopy. These two assumptions together with the data in Tables 2 and 4 yield an estimate of 1.4 to 2.7 kg/ha for NH4, and 0.1 to 0.2 kg/ha for H.

The primary source for the deposition of Cl, Na, K, Ca, and Mg is the forest canopy as indicated in Tables 4 and 5. Due to the neutralization of deposited H and absorption of NH4 by the canopy, a substantial portion of the base cations being deposited to the forest floor is the direct result of acidic cloud water interception. Nutrient cycling of these cations within the canopy prevents a definite conclusion as to which cations are enhanced in throughfall due to acidic cloud water deposition, but the combined estimates of H and NH4 deposition given above do equal or exceed the combined estimates for Ca and Mg deposition in Table 5, when expressed on an equivalent basis. Thus, it is probably fair to assume that a substanital portion of Ca and Mg in the measured throughfall is due to the interaction of acidic cloud water with the forest canopy.

The estimates in Tables 4 and 5 were calculated using data from only the rain collector at Site 1, and the throughfall collectors at Sites 1 and 2. Estimates of deposition via stemflow were not included because of the difficulty of expressing these results on an area basis. An estimate of deposition via stemflow was obtained by including in the calculations for Site 2 the number of boles per unit area used for sample collection. Estimates for SO4 deposition via stemflow using this approach yielded values of less than 1 percent of those for throughfall, even though the volumes collected via stemflow during cloud and rain events were often an order of magnitude greater than those collected from throughfall. It therefore appears that while stemflow may have a direct influence on deposition to the forest floor at the base of a tree, its overall contribution to the total deposition within the canopy is minimal.

Conclusions

The data in Tables 1-5 provide the first measurements of cloud induced deposition of acidic N and S compounds within the high-elevation red spruce and Fraser fir forests on Mt. Michell. Total deposition for NO3 and SO4 under the forest canopy ranged from 4 to 6 kg/ha for NO3 to 16 to 22 kg/ha for SO4. Correction for the deposition from rain yields estimates of 40 to 70 percent of the deposition of NO3 and SO4 as being due to cloud interception, assuming minimal dry deposition in this ecosystem. Indirect estimates of cloud induced deposition of H and NH4 range from 0.1 to 0.2 and 1.4 to 2.7 kg/ha, respectively. Assuming the same percentage of cloud and rainfall deposition throughout the year yields estimates of 1, 8, 20 and 75 kg/ha/yr for H, NH4, NO3, and SO4, respectively.

Further interpretations of the data should be approached with caution, however, as the data set is limited by the number of trees samples in 1986, and by the fact that the 1986 field season was a period of very low rainfall. Lack of prior climatological data at Mt. Mitchell precludes any conclusions regarding the normalcy of the cloud type and frequency actually observed at the two sampling sites. Cloud water collection has continued in 1987 along with an expanded throughfall and stemflow sampling design at both sites. This design includes an increase in the number of trees sampled (20 throughfall and stemflow collectors per site) and the sampling areas. The collection area at Site 2 was moved to a more representative red spruce stand upslope from the meteorological tower. Open collectors were included at each site to obtain separate rain samples for each rain event. Sample collection was begun in May, 1987, and continued on an event basis until August 24, 1987. Sample collection was then continued on a weekly basis until mid-November. Sample collection at 2 trees per site was supplemented by a 5x5-m sampling grid to estimate the variance in volume collected per tree per event. When completed, the analytical results from this expanded throughfall and stemflow design (1,600 samples) should provide a statistically sound database from which to make a first approximation of the elevational gradient of cloud water deposition at Mt. Mitchell.

Lastly, the ionic composition of acidic cloud water and rain water is significantly altered upon interaction with the forest canopy. The minimum pH observed for throughfall was 3.2, but the mean volume-weighted pH is 3.9 (Table 1). There is also a substantial enrichment in base cations as the rain water passes through the canopy (Tables 2 and 3). Thus the actual solution reaching the forest floor within the canopy has a composition significantly different from that often used in dose response studies attempting to determine the effect of acidic rainfall on soil properties or root growth. Future such studies may yield more meaningful results if treatments include solutions more in keeping with the composition of throughfall reported here.

Denitrification in Southern Appalachian Spruce-Fir Forests

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Abstract

Denitrification was measured in situ on 19 plots by the acetylene block technique in the Southern Appalachian Spruce-Fir forest. A double-walled tube was driven into the soil and acetylene injected through the outside tube diffused though holes in the inner tube and into the top 0-15 cm of soil. NO2 release was measured at intervals after acetylene injection. Denitrification in May, July, August, and September was < 0.5 *kg/ha/yr. Treatments of soil with H2O, NO3, and glucose increased denitrification. Low rates of denitrification are attributed to low quantities of available carbon, low NO3, high soil aeration, high acidity, and low temperature.*

Introduction

Spruce-fir forests at high elevations in the East receive large nitrogen (N) inputs from the atmosphere. Red spruce (*Picae rubens* Sarg) and Fraser fir (*Abies fraseri* (Pursh) Poir) forests grow relatively slowly and there are indications that growth rate has declined in the last two decades. As a result of high N deposition and slow tree growth, excess ammonium (NH4) and nitrate (NO3) N may cause nutritional imbalance, excess leaching of nutrients, and soil acidification, which independently or in combination contribute to forest decline. Under the conditions described, dentrification would tend to alleviate excess N and the associated detrimental effects. Knowledge of the denitrification potential and N mineralization (Strader, Binkley, and Wells[1]) of these soils will help evaluate hypotheses about N and forest decline. The objectives of our study were to determine if denitrification is a major process balancing of N input and output in southern spruce-fir forests and to determine what factors limit denitrification in these forests.

Methods

Field

Denitrification was investigated at Clingman's Dome, Mt. Mitchell, and Whitetop Mountain on the same 19 plots that Strader, Binkley, and Wells[1] used to measure N mineralization. Stand and soil characteristics are shown in Table 1. In May, July, and September 1986, dentrification was measured in situ by an acetylene block technique using a double-walled PVC tube assembly for acetylene injection (Burton and Beauchamp 1984). The double-walled tube was driven into the soil to a depth of approximately 15 cm. Acetylene injected into the space between walls through a septum passed through holes in the inner tube into the soil core which was 4.2 cm in diameter. The head space above the soil was sealed when acetylene was injected and then sampled at intervals with a syringe needle and 12 cc vacuum tube. Acetylene was generated from calcium carbide. In the acetylene-block technique, acetylene inhibits N2O reduction to N2. Since N2O is in the major pathway of denitrification, N2O is an acceptable measure of denitrification (Burns and Terry 1986).

The headspace was sampled 0.5, 1.5, and 2.5 hours after acetylene injection. In some plots headspace was also sampled after an overnight period. Changes in concentrations of N2O between sampling times were used to calculate release rate, which was assumed to represent denitrification. At each sampling in May, July, and September, 10 tubes were installed on a 20-m contour line for each plot. In August at Mt. Mitchell, N2O release without acetylene, and the effects of H2O, NO3, and glucose additions to N2O release were measured on three high-west and three low-east plots. The treatments in four replicates applied to the tubes before acetylene injection were: 1) control, 2) +100 mL of water/tube, 3) +100 mL of 0.7 mM nitrate, and 4) +100 mL of 0.7 mM nitrate plus 0.1% glucose. Treatments 5 and 6 were the same as 2 and 3, except no acetylene block was used. These treatments were applied to 10 x 10-cm areas which were then covered with a plastic box pressed into the soil.

Laboratory

For N2O analysis the gas sample was transferred from the tubes to a Tracor 565 gas chromatograph with a gas tight syringe. The gas chromatograph was equipped with an electron capture detector at 350°C, a 1.9 m Poropak T, and a 3.1 m Poropak Q column (0.32 cm i.d.) in sequence at 50°C. Carrier gas of 95 percent argon and 5 percent methane was introduced at flow rates of 20 cc/minute for the columns and a 40 cc/minute makeup rate for the detector. A 10-port valve was configured to permit the heavier acetylene and H2O vapors to be backflushed from the first column while N2O and lighter gases were separated on the analytical column.

Standards were prepared from N2O gas diluted first in 100 cc volumes of air and then into tubes identical to those used to sample in the forest. The standards were prepared at the same time that samples were collected and were stored in the laboratory along with the samples. N2O analyses of standards in storage indicated stability for at least 2 months.

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[1] Strader, Russell; Binkley, Dan; Wells, Carol G. 1987. Nitrogen mineralization in soils of the southern spruce-fir forests. Final report of Spruce-Fir Research Cooperative, U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Broomall, PA. 26 p.

Table 1.--Elevation, aspect, and general living stand characteristics of study sites

Location	Exposure	Plot no.[a]	Elevation	Aspect	Spruce[b]	Fir	Stand density	Dominant/ codominant
			m		--*m²/ha*--		*Stems/ha*	*Years*
Clingman's Dome	Low/east	S 17	1707	E	41.7	0.1	275	198-295
		S 32	1677	E	45.9	0.0	875	NA
		801	1634	E				
Clingman's Dome	High/ridge	S 05	2006	E	15.5	16.9	425	56-264
		S 06	1982	N	0.8	19.2	1450	43-149
		S 16	1957	N	5.7	17.3	525	91-218
Mount Mitchell	Low/east	B 32	1680	SE	58.5	0.0	1075	53
		901	1686	SE				
		902	1671	S				
Mount Mitchell	High/east	B 34	1829	SE	28.8	1.2	2075	38-58
		B 35	1854	SE	19.9	0.1	1975	53-63
		906	1951	NE				
Mount Mitchell	High/west	903	1921	SW				
		904	1915	SW				
		905	1927	SW				
Whitetop	High/west	R 13	1668	NW	24.8	0.0	2025	42-78
		R 20	1579	W	30.4	0.0	1400	77-135
Whitetop	High/east	R 17	1640	SE	48.4	0.0	7950	24-28
		R 27	1674	E	53.2	0.0	4450	40-52

[a] Plots with numbers beginning with B, R or S are adjacent to permanent plots of Spruce/Fir Research Cooperative.

[b] Unpublished data provided by: S. Zedaker, N. Nicholas, and C. Eggar. Site and stand characteristics of Southern Appalachia Spruce/Fir project funded by Spruce/Fir Research Cooperative.

Statistical

Data for N2O release failed normality tests; therefore, parametric or nonparametric tests on rank transforms (Conover 1980) were conducted. Preliminary analyses of the data from the study at Mt. Mitchell indicated that experimental error variances were not homogeneous between the two elevations and suggested the presence of a treatment x elevation interaction. Accordingly, an extension of Friedman's nonparametric analysis on rank transforms from a randomized complete block design with four replicates (Conover 1980) was used separately for each elevation. Statistical analyses were by SAS (SAS Institute 1983).

Results

Denitrification was below detection limits in all 19 plots (Table 2). The highest rate observed for any location at any time was 10.23 μg/L (standard deviation 0.60) in the high east plots on Mt. Mitchell in May. This value would be equivalent to 0.5 kg N lost/ha annually if the rate were constant for 365 days, an unrealistic assumption.

Additions of nitrate and glucose during the August experiments boosted rates above detection limts, but high variability limited the precision of the treatment comparisons (Table 3). Water had little effect. In general, overnight release of N2O was small, possibly because acetylene activity was low after adsorption in these highly organic soils. Another possible explanation is N2O leakage from the tubes. Leakage appears to have occurred from the tubes for the low east hour two and high west overnight data.

Table 2.--Denitrification potentials in the summer of 1986 (soil temperature was 9°C in May, 17°C in July, and 12°C in September)

Mountain and exposure	Plot	May		July		Sept., hr 1		Sept., hr 2	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
		µg N_2O-N L^{-1} hr $^{-1}$							
Mt. Mitchell									
Low/east	B 32	-0.05	0.06	0.00	0.08	0.01	0.02	0.03	0.05
	901	0.03	0.05	0.09	0.17	-0.23	0.92	-0.12	1.88
	902	0.06	0.02	0.03	0.07	0.00	0.03	0.01	0.09
	Avg.	0.01	0.07	0.04	0.12	-0.07	0.51	-0.02	1.01
High/east	B 34	-0.01	0.08	0.02	0.06	0.01	0.02	0.01	0.05
	B 35	0.00	0.07	0.02	0.08	-0.26	0.71	-0.71	1.15
	906	0.69	0.86	0.31	0.51	0.22	0.35	0.21	0.42
	Avg.	0.23	0.60	0.12	0.32	-0.01	0.50	0.02	0.69
High/west	903	0.01	0.07	0.02	0.17	-0.04	0.34	0.09	0.30
	904	0.10	0.25	-0.04	0.19	-0.06	0.15	-0.16	0.39
	905	0.07	0.18	0.03	0.05	0.04	0.68	-0.05	1.15
	Avg.	0.06	0.18	0.00	0.15	-0.02	0.43	-0.04	0.69
Clingman's Dome									
Low/east	S317			0.01	0.07	0.02	0.17	-0.37	0.93
	S332			0.05	0.14	-0.04	0.22	-0.03	0.48
	801			0.06	0.12	-0.04	0.22	-0.03	0.63
	Avg.			0.04	0.12	-0.02	0.17	-0.23	0.70
High/ridge	S305			0.16	0.56	0.14	0.22	0.12	0.18
	S306			-0.04	0.85	0.28	0.44	0.26	0.44
	S316			0.00	0.19	0.17	0.21	0.19	0.48
	Avg.			0.04	0.60	0.20	0.31	0.19	0.38
Whitetop Mountain									
High/east	R 17			0.01	0.03	0.00	0.05	0.00	0.05
High/east	R 27			0.04	0.06	0.01	0.02	0.02	0.03
High/west	R 20			0.01	0.20	0.02	0.04	0.04	0.06
High/west	R 13			0.05	0.05	0.06	0.07	0.08	0.15

No N2O accumulated above ambient levels in the inverted boxes installed in August to measure the release of N2O in the absence of acetylene block. At other sampling dates, double-walled tubes were installed without acetylene and N2O release was not detectable.

Discussion

This study was designed to examine denitrification on slopes and ridges; no samples were collected in cove and stream side sites. Spatial variation was large in relation to N2O release, with the standard deviations typically twice as large as the means. Frequently, 2 of the 10 samples per plot had N2O concentrations twice that of ambient air while the others had concentrations near that of ambient air. Extrapolation of even the extreme rates over time and area would still yield very low rates of denitrification. Although precipitation was low during the summer of 1986, these very porous soils maintained at least 40 to 60 percent moisture by weight at the 0-15 cm depth. In some cases sampling was conducted immediately after rain. The addition of water in the August experiment did not increase N2O release, but the soil was not saturated even 2 hours after the water addition. Consequently, the redox potential of the soil probably remained high. Some denitrification studies have found that much of the annual flux can occur in a few isolated events, so it is possible that denitrification is higher than our data indicate.

Table 3.--Effect of additions of water, nitrate and glucose on N_2O production at Mt. Mitchell in August (4 samples/plot, 3 plots/elevation-exposure[a])

Elevation, exposure, and time	Control		+ Water		+ Water + nutrient		+ Water + nitrate + glucose	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	μg NL^{-1}hr^{-1}							
High/west								
Hour 1	-0.11	0.49	-0.03	0.93	0.69	2.15	1.41	2.19
Hour 2	0.21a	0.75	0.27a	0.48	2.58a	7.98	4.11b	4.83
Overnight	0.00	0.00	-0.04	0.07	-0.18	0.53	-0.27	0.44
Low/east								
Hour 1	0.02	0.14	0.04	0.90	0.18	0.31	3.15	9.54
Hour 2	0.00ac	0.09	0.10bc	1.17	1.07b	2.54	-1.26ac	3.71
Overnight	0.04	0.06	0.34	0.76	0.24	0.36	6.36	17.80

[a] Exposure with differing letter in line differ significantly (P = 0.10); means without letters in the same line did not show significant difference for exposures at 10 percent level.

Temperature, soil moisture, pH, carbon energy source, and nitrate are the important environmental controls of denitrification. In our study, the temperature ranged from of 0° to 17°C; soil moisture was high when samples were collected immediately after rain and when water was applied; soil was very acid (pH 3.8 to 4.5); availability of carbon and competition for carbon from all microflora were unknown; and nitrate was sufficient to support denitrification at detectable levels.

Davidson and Swank (1987) investigated factors limiting denitrification in soil cores from southeastern hardwood forests in the laboratory. They concluded that denitrification may be important in surface horizons of wet soils (restricted 02) containing NO3. Low carbon supply impeded but did not prevent denitrification, and denitrification should not be dismissed because of acidic conditions. Increasing base saturation increased denitrification. Soil pH for the Davidson and Swank (1986) study was 5.1 to 6.3 somewhat less acid than in spruce-fir forests. Robertson et al. (1987) incubated soil cores from southeastern loblolly pine forest and also found N2O release proportional to NO3. Denitrification was estimated to be 0.4 to 0.7 kg N/ha/yr for an undisturbed plot and 3 to 6 kg N/ha/yr for harvested and site prepared plots. The low denitrification for the undisturbed plot was attributed to the absence of measurable soil NO3.

On our six study sites, mean annual NO3-N concentration was 8 to 15 mg/kg (Strader, Binkley and Wells[1]), which is sufficient for denitrification to occur. Environmental conditions in the soil did not favor denitrification or nitrification; but nitrification rates were relatively high. Bowden's (1986) review reports that investigators have shown N2O is produced during nitrification in well-aerated soils. The lack of detectable N2O release in the absence of acetylene block indicates that N2O release during nitrification was zero or extremely small in our soils. Cates and Keeney (1987) reported very low or zero N2O emissions from native prairies in southern Wisconsin under field incubation. Sahrawat et al. (1985) found N2O emission proportional to NO3 formation when soils were incubated at 30°C in the laboratory. The N2O-N was only a small proportion of nitrification in the aerobic system on six acid climax forest sites in Wisconsin.

Addition of water, NO3, and glucose indicated NO3, and to a greater extent glucose, increased denitrification. The high variability we observed may be associated with micro-site differences in denitrifiying bacteria populations and drainage (Davidson and Swank 1987). Poor availability of a carbon energy source, high acidity, well-aerated soil conditions, and low temperature apparently prevented denitrification in the soils investigated.

The investigation of soil denitrification was enhanced by development of the acetylene-block method (Burns and Terry 1986; Parkin et al. 1985), but in situ measurements of denitrification are plagued by very high spatial variability and the difficulty of isolating the desired soil volume and introducing acetylene into the soil. The double-walled core method used in this study was compared with three other methods in the field and found to produce the highest rate of denitrification and the least variation (Burton and Beauchamp 1984). In our spruce-fir forest soil, which contains large roots and stones, some sample points were rejected because the tubes could not be driven into the soil and the tubes required frequent repair or replacement.

It would be desirable to sample the soil to a greater depth, but it did not seem practical in these soils. Variability found in this study consisted of spatial sampling and analytical variability. With greater denitrification, sampling and analytical error would be less important.

The extremely low denitrification in these well-aerated forest soils is similar to that in other forest soils. Denitrification may be an important N-cycling process for the entire ecosystem, which includes coves and streamsides where denitrifying bacteria are abundant and denitrification is high in comparison with slopes and ridges (Davidson and Swank 1986, 1987). It appears, however, that denitrification on most southern Appalachian spruce-fir sites is very small in relation to atmospheric deposition and nitrate leaching. It is probably smaller than the errors associated with estimates of nitrate leaching from the soil.

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Stand Characteristics Associated With Potential Decline of Spruce-Fir Forests in the Southern Appalachians

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Abstract

A detailed assessment of current stand condition at three sites in the spruce-fir forests of the southern Appalachian has been done. Species composition of these stands changes dramatically with elevation from dominance by red spruce at low elevations to dominance by Fraser fir at higher elevations (>6,000 ft). Total stand basal area decreases with increasing elevation and the pattern is consistent with site quality. The percent of dead basal area increases with increasing elevation for both spruce and fir. Red spruce crown vigor has decreased between 1985 and 1986 in the Black Mountains (NC) and the Great Smoky Mountains (TN, NC), but not on the Mount Rogers National Recreation Area (VA). The decreases in crown vigor are more pronounced at low elevation and in stands dominated heavily by fir. Fir mortality is highly correlated with the occurrence of the balsam woolly adelgid. The current total basal area in even-aged stands is consistent with basal area projections for stands of similar age and site quality.

Introduction

Circumstantial evidence for the decline of Southern Appalachian spruce-fir forests as a result of atmospheric deposition of pollutants has recently been reported by many authors (Bruck 1985, McLaughlin 1985, Adams et al. 1985). Although it is generally accepted that the growth of Southern Appalachian spruce-fir forests has decreased over the past two decades, the connection of this decline to pollution is circumstantial since at least a portion of the decline is attributable to natural stand processes (Hornbeck et al. 1986, Zedaker et al. 1987, Hyink and Zedaker 1987). Key issues in the debate over the involvement of air pollution center around the expected normal behavior of spruce-fir stands, relative to their natural conditions and dynamics, and their behavior relative to gradients of pollution deposition. Extreme variation in the characteristics of the present stands, ranging from second growth plantations on areas logged and burned to virgin natural stands, necessitates a detailed assessment of stand characteristics before reasonable expectations of normal behavior can be developed.

With this background in mind, the general objectives of this study are to: 1) characterize the existing stand conditions in Southern Appalachian spruce-fir forests and develop an expectation of their normal development; 2) determine if changes in growth and mortality, and the presence of unusual foliar symptomology in these spruce-fir stands are greater than can be attributed to their expected behavior and levels of natural variability; and 3) to determine what spatial patterns, if any, exist in growth and mortality and the presence of unusual symptomology in Southern Appalachian spruce-fir forests and how these patterns might relate to spatial patterns of pollutant exposure. Within the NAPAP Forest Response Program and the Spruce-Fir Cooperative, this project is directed toward an answer to Policy Question 1: is there a significant problem of forest damage in North America which might be caused by acid rain, its precursers, and associated pollutants?

Although the Southern Appalachian spruce-fir forest is not of commercial importance from a timber standpoint, it is an extremely valuable recreation and esthetic resource. Since the deposition of atmospheric pollutants seems to increase with increasing elevation, the high elevation spruce-fir forest of the Southern Appalachians may also be important as an indicator forest for potential pollution problems in the low elevation commercial forests in the South.

Methods and Materials

The central problem posed by the research objectives is to determine whether or not the Southern Appalachian spruce-fir ecosystem is changing in a detrimental way. To solve this problem, we developed a sampling and data analysis strategy that will allow long-term monitoring of changes in the composition, vigor, and growth of these forest stands. The sampling strategy accounts for known sources of variation as well as potential variation due to differences in atmospheric deposition. Atmospheric monitoring by the Mountain Cloud Chemistry Project has shown that pollution deposition varies with geographic region, elevation and cloud interception (as influenced by land form, aspect and topography). The site quality, stand composition and potential stand vigor are also known to be influenced by geography, elevation, aspect and topography.

Permanent (400 m^2) plots were established on three geographically distinct areas: Mt. Rogers National Recreation Area (Virginia), the Black Mountains of North Carolina, and Great Smoky

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Mountains National Park in Tennessee and North Carolina. At each study area, the plots were stratified by elevation, exposure to prevailing winds, and slope position with three randomly located replicates per stratification combination.

Vegetation data was taken in three structural classes: overstory (≥ 5 cm DBH), understory (< 5 cm DBH and ≥ 1.37 m tall), and herb strata (< 1.37 m tall). All trees on the plot were tagged, identified by species, measured for DBH, rated on a four-point scale developed at the 1984 Forest Decline Methodology Workshop, and were assessed for disturbance symptomology. Ten randomly selected dominants and codominants were cored for age, and measured for total height, live crown ratio, and live crown width. Understory samples were taken in three 16 m^2 subplots and all woody stems were recorded by species, height, live crown ratio, and crown width. Herb and seedling strata samples were measured in two nested 1 m^2 sub-subplots for each understory subplot. All woody stems were counted, by species, and recorded in one of five age-size classes. Herbaceous vegetation was recorded for each species by percent cover. Seed traps were installed adjacent to the intensively measured area at a subsample of the plots for assessment of seed fall and viability by species.

A total of 129 permanent plots among the three study sites were established in 1985 and 1986. Overstory stem crown condition, seed fall, seed viability, and seedling recruitment were assessed in 1986 and 1987. All strata were fully remeasured in the summer of 1987 and will be remeasured again in 1989.

Near selected permanent plots, all overstory trees on a 10 x 10 m area, were measured as on the 400 m^2 plot and then harvested. Stem analysis was conducted on six trees per plot by sectioning at two meter intervals and at breast height to determine historical growth data. The remaining trees were left to decay on site. Dimension analysis will be performed to determine biomass of tree boles, branches, and foliage. Foliage subsamples were taken for specific leaf area analysis. Leaf area-sapwood area ratios, and biomass equations using foliage, branch, and bole components will be developed by regression analysis of biomass components. Dimension analysis will be performed on woody stems in the understory strata in two 4 x 4 m subplots to assess understory biomass. Fifteen out of eighteen planned destructive plots were completed by October 1987.

The three study sites are also being inventoried using transects. Variable plot sampling of the overstory is performed every 250 ft (76m) change in elevation. This large-scale inventory data allows comparison of the intensively sampled permanent plots to a broad view of each study area. Eight transects have been sampled at Mt. Rogers National Recreation Area (NRA), twenty at the Black Mountains, and seven out of twenty at the Great Smoky Mountains.

Details of the actual measurement techniques used in this study can be found in the U.S. Environmental Protection Agency approved Quality Assurance/Quality Control (QA/QC) Manual for Site Classification and Field Methods field studies (Zedaker and Nicholas 1986).

Results and Discussion

Results of the assessment of current stand conditions and the 1986 remeasurement of tree crown condition and mortality are included in this report.

The current live and dead basal area for Mount Rogers NRA, the Black Mountains, and for the Great Smoky Mountains is presented in Tables 1-3. The spruce-fir forests on all three mountain regions is dominated at low elevations by red spruce (*Picea rubens* Sarg.) and at high elevations by Fraser fir (*Abies fraseri* (Pursch) Poir.). The total stand basal area increases with decreasing latitude. Total basal area decreases with increasing elevation, except on the disturbed sites on Mount Rogers (Table 1). The percent of the total basal area in standing dead trees increases with increasing elevation on all mountains. The percent of dead basal area for red spruce growing at 5000 feet (1524 m) ranges from 3% in the Black Mountains to 9% in the Rogers area.

At 6500 feet (1981 m) in the Blacks and Smokies the percent of red spruce basal area in standing dead trees averages 17%. The percent of basal area in standing dead trees is much higher for Fraser fir at high elevations. Dead fir represents 32% of the fir basal area on Rogers, 48% in the Black Mountains, and 59% in the Great Smoky Mountains. The incidence of Fraser fir mortality is highly correlated with the occurrence of balsam woolly adelgid (*Adelges piceae* Ratz.).

When pooled for all stands samples, the age class distributions for spruce and fir show wide variation in individual tree ages (Figs. 1-3). However, many low elevation stands are essentially even-aged. Logging in the lower elevations between 1900 and 1930 created many even-aged stands in terms of stand development. Over 60% of the stands on the Mount Rogers NRA and the Black Mountains show signs of logging and/or burning (Pyle et al. 1985). Because many of these stands regenerated naturally from advanced regeneration in the original understory, and both red spruce and Fraser fir are very tolerant, these stands may still show a wide distribution of age classes. Since their release or physiological age is the same, the stands should be functionally even-aged (Hyink and Zedaker 1987). In addition, some actual even-aged spruce and fir plantations were found on both mountains. Conversely, most of the high elevation stands seem to be relatively undisturbed (by logging) uneven-aged stands. In the Great Smoky Mountains, less than 20 percent of the spruce-fir forest shows signs of logging and /or burning (Pyle et al. 1985).

Tables 4-6 illustrate the change in live red spruce crown conditions from 1985 to 1986. The crown condition of trees on Mount Rogers NRA did not change during the one period (Table 4). The crown condition of spruce growing in the Black Mountains and Great Smokies decreased about ten percent. Decreases in red spruce crown condition were most pronounced in low elevation stands and stands dominated by Fraser fir. Crown conditions in the Black Mountains and in the Mount Rogers NRA seems to be correlated to stand density (Table 7).

Table 1.--Basal area (m^2/ha) and density (stems/ha) for *Picea rubens, Abies fraseri,* and all species combined from permanent plots at Mt. Rogers National Recreation Area

	5000 feet				5500 feet			
	Exp[a]		Prot[a]		Exp		Prot	
Species	BA	DEN	BA	DEN	BA	DEN	BA	DEN
Live PICRBN	20.8	675	5.3	125	11.5	608	23.4	1932
ABSFRS	13.5	835	24.4	1260	21.2	1383	19.5	604
Total	42.0	1833	36.2	2125	38.1	2799	44.2	2679
Dead PICRBN	1.9	80	0.7	10	4.4	150	8.6	629
ABSFRS	2.0	415	2.2	270	4.9	642	8.6	404
Total	8.0	665	4.9	463	9.6	859	18.3	1094

[a] Exp = Exposed aspect to prevailing winds; Prot = Protected aspect from prevailing winds.

Table 2.--Basal area (m^2/ha) and density (stems/ha) for *Picea rubens, Abies fraseri,* and all species combined from permanent plots at the Black Mountains.

	5000 feet				5500 feet				6000 feet				6500 feet			
	Exp		Prot		Exp		Prot		Exp		Prot		Exp		Prot	
Species	BA	DEN	BA	DEN	BA	DEN	BA	DEN	BA	DEN	BA	DEN	BA	DEN	BA	DEN
Live PICRBN	14.7	313	50.2	696	27.0	938	36.3	607	5.2	438	19.2	568	7.1	75	2.7	75
ABSFRS	-	-	0.1	21	0.5	38	0.3	39	4.8	375	5.7	589	29.2	1325	12.9	1038
Total	35.6	965	60.9	883	45.9	1934	46.5	1234	16.3	1651	33.1	1628	37.7	1500	18.1	1401
Dead PICRBN	0.4	25	1.9	108	2.4	88	1.7	75	3.0	188	5.6	71	-	-	10.4	150
ABSFRS	-	-	-	-	0.6	13	-	-	13.2	738	3.7	93	15.5	300	21.4	1763
Total	2.1	89	4.2	179	9.0	451	5.7	343	19.1	1327	17.1	510	16.6	350	36.5	2227

Table 3.--Basal area (m²/ha) and density (stems/ha) for *Picea rubens, Abies fraseri,* and all species combined from permanent plots at the Great Smoky Mountains.

	5000 feet				5500 feet				6000 feet				6500 feet			
	Exp		Prot		Exp		Prot		Exp		Prot		Exp		Prot	
Species	BA	DEN	BA	DEN	BA	DEN	BA	DEN	BA	DEN	BA	DEN	BA	DEN	BA	DEN
Live PICRBN	44.9	553	47.1	456	53.1	292	48.1	403	24.5	208	39.8	331	8.5	146	25.9	204
ABSFRS	.1	19	-	-	.9	94	.1	36	6.2	233	1.3	158	18.7	1233	9.9	408
Total	55.6	633	63.7	525	62.1	508	58.6	564	34.6	617	45.4	658	28.6	1517	36.7	633
Dead PICRBN	2.3	58	6.5	75	3.2	50	4.9	75	2.2	19	3.9	53	1.9	13	.3	13
ABSFRS	2.7	158	2.2	103	12.9	667	11.3	672	18.1	650	9.3	483	20.4	796	21.4	667
Total	6.3	256	9.9	225	18.7	794	17.0	800	22.3	792	14.8	611	25.5	1121	23.6	771

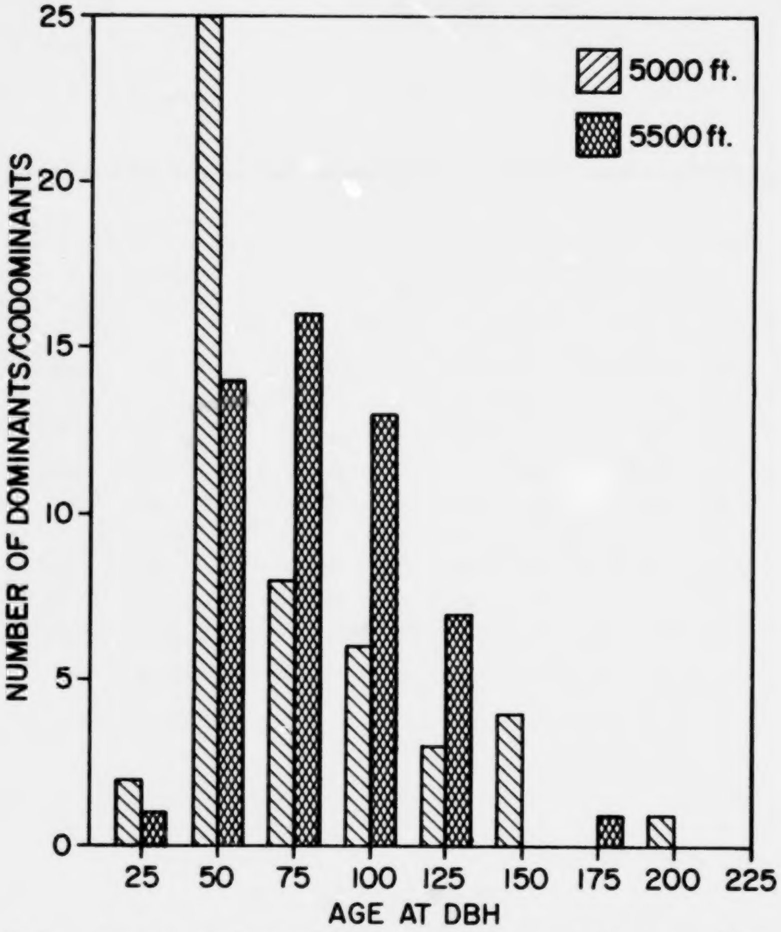

Figure 1.--Age class distribution of dominant and codominant red spruce and Fraser fir for Mount Rogers National Recreation Area.

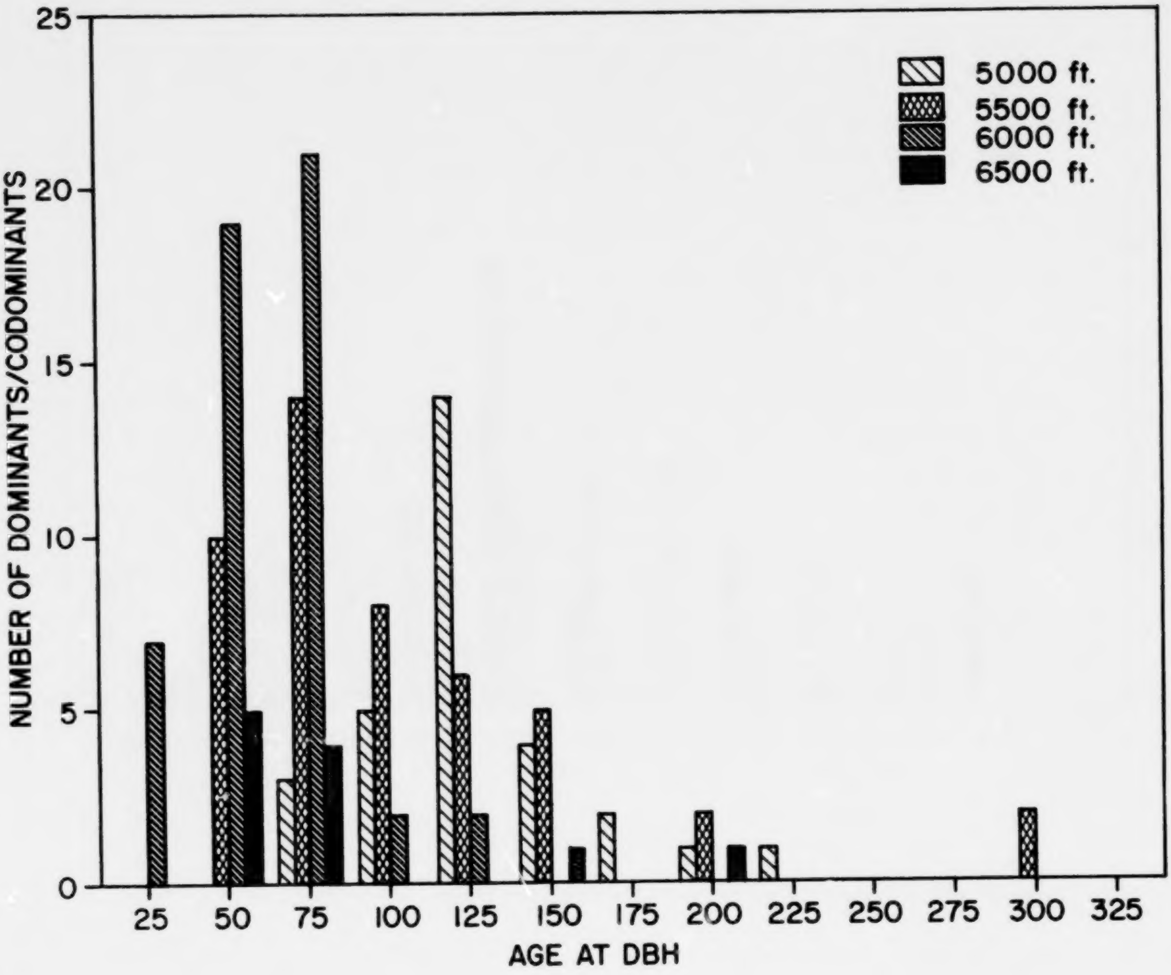

Figure 2.--Age class distribution of dominant and codominant red spruce and Fraser fir for the Black Mountains.

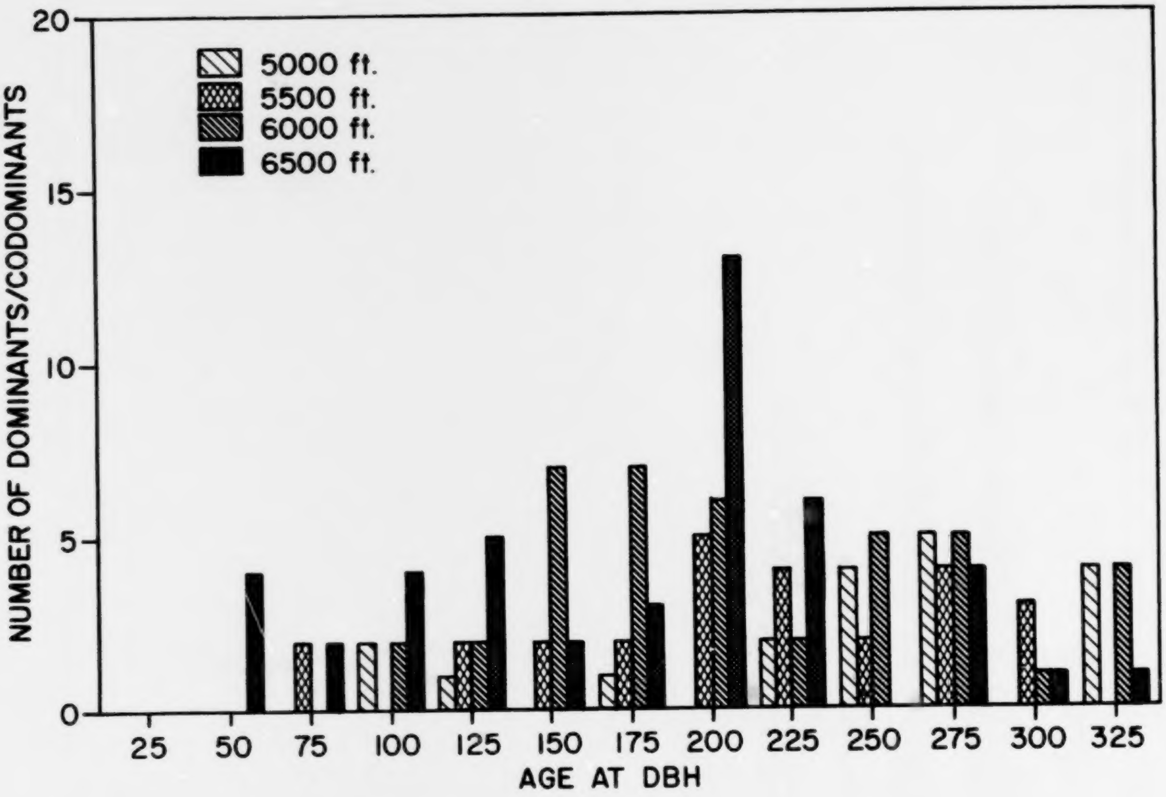

Figure 3.--Age class distribution of dominant and codominant red spruce and Fraser fir for the Great Smoky Mountains.

Table 4.--1985-1986 live crown condition for *Picea rubens* (in percent of live stems ≥ 5 cm DBH) for Mt. Rogers National Recreation Area

		Aspect			
		Exposed		Protected	
Elevation (feet)	Crown class[a]	'85	'86	'85	'86
5000	1	85.2	74.9	100.0	100.0
	2	14.1	25.1	-	-
	3	0.7	1.5	-	-
		n = 135	n = 136	n = 25	n = 23
5500	1	94.5	93.6	93.7	89.5
	2	5.5	6.0	5.5	9.2
	3	-	0.4	0.7	1.3
		n = 73	n = 160	n = 532	n = 543
1985 N = 765					
1986 N = 862					

[a] Class 1: 100-90% crown intact; Class 2: 89-50% crown intact; Class 3: 49-1% crown intact.

Table 5.--1985-1986 live crown condition for *Picea rubens* (in percent of live stems ≥ 5 cm DBH) for the Black Mountains

		Aspect			
		Exposed		Protected	
Elevation (feet)	Crown class	'85	'86	'85	'86
5000	1	100.0	90.7	83.8	76.7
	2	-	6.3	15.0	19.7
	3	-	3.0	1.2	3.6
		n = 25	n = 26	n = 180	n = 165
5500	1	95.6	86.7	89.9	92.4
	2	4.0	9.0	8.8	7.6
	3	0.4	4.3	1.3	-
		n = 225	n = 197	n = 171	n = 163
6000	1	65.7	96.9	88.7	87.5
	2	22.9	3.1	10.1	8.8
	3	11.4	-	1.3	3.7
		n = 35	n = 50	n = 159	n = 224
6500	1		100.0	83.3	90.9
	2		-	16.7	9.1
	3		-	-	-
			n = 3	n = 6	n = 17
1985 N = 801					
1986 N = 845					

Table 6.--1985-1986 live crown condition for *Picea rubens* (in percent of live stems ≥ 5 cm DBH) for the Great Smoky Mountains

		Aspect			
		Exposed		Protected	
Elevation (feet)	Crown class	'85	'86	'85	'86
5000	1	86.4	60.3	93.2	79.3
	2	13.6	35.7	6.8	20.1
	3	-	4.0	-	0.6
		n = 95	n = 199	n = 112	n = 164
5500	1	84.1	68.6	86.8	75.9
	2	14.9	25.7	13.2	20.7
	3	1.0	5.7	-	3.4
		n = 106	n = 105	n = 145	n = 145
6000	1	81.6	78.7	80.1	78.1
	2	17.0	20.0	19.9	20.2
	3	1.4	1.3	-	1.7
		n = 76	n = 75	n = 119	n = 119
6500	1	90.9	68.6	80.9	67.3
	2	9.1	31.4	19.1	26.5
	3	-	-	-	6.2
		n = 14	n = 35	n = 47	n = 49
1985 N = 714					
1986 N = 891					

An evaluation of the current condition of the Southern Appalachian spruce-fir forest cannot be done without some expectation of what a "normal" stand should look like. Although good models for "normal" even-aged stands, developed prior to 1930, are available, data on the expected conditions in uneven-aged stands are limited. The low elevation, even-aged stands exhibit total basal areas consistent with Meyer's 1929 growth and yield study (Table 7). Site quality decreases with increasing elevation, but increases with decreasing latitude. The carrying capacity (in basal area) is highly correlated to site quality. Departures from the expected basal area increase with increasing elevation. Some, but not all, of the basal area shortfall can be attributed to the Fraser fir mortality as influenced by the balsam woolly adelgid. Site index (quality) estimates are good in actual even-aged stands but are negatively biased in stands in which understory residuals (left from the logging) are now dominant. In addition, the patch dynamics of uneven-aged stands may lead to lower total stand basal areas than expected for even-aged stands when averaged over the entire spruce-fir forest.

The basal areas, either live stems only or live plus standing dead stems, for the randomly located plots used in this study are greater than those recently reported for red spruce stands in the Southern Appalachians by McLaughlin and others (1987). Our recorded basal areas in the Smoky Mountains are consistent with those reported by Oosting and Billings (1951). Based on the differences in sampling techniques, the plots from this study appear more representative of the stand conditions found throughout the southern Appalachians then those of McLaughlin and others (1987). Since the actual site quality (as measured by site index) of the McLaughlin plots was not reported, it is not possible to determine whether a bias exists in the area sampled or some error in their use of the point sampling method of basal area measurement was made. The 25% to 50% higher stand basal areas found in this study do not support McLaughlin and others' claim that competition is not a factor in observed declines.

Individual tree and stand growth data from the 1987 remeasurement is not available at this time and may not show a great enough change to be separated from normal variance. Several remeasurements, including the one scheduled for 1989 may be needed to accurately assess the growth of Southern Appalachian Spruce-fir forests.

An assessment of the growth trends found cannot be made without the development of an expectation of "normal" stand and tree characteristics. One expectation of normal stand development is that the growth of individual trees in the even-aged stands should be decreasing and the even-aged stand growth should be decelerating. The basal area development in stands not impacted by the balsam woolly adelgid has gone beyond the point of the culmination of mean annual increment (Meyer 1929). Two scenarios for the development of adelgid impacted stands seem plausible. If the fir composition is low, the remaining spruce may react positively to a decrease in the apparent stand density. A long-lived, tolerant, species like red spruce should be able to respond to the reduction in competition by increasing its growth. However, if Fraser fir density is high, the residual spruce may suffer from the rapid exposure to wind, snow and ice damage when the fir are killed. Growth declines in both cases may indicate that factors other than competition are operative.

Stand growth in virgin, uneven aged stands, if they had reached their steady state equlibrium, may be constant. However, the radial growth of older individual trees in uneven-aged stands will still decrease. Although the rate of basal area growth may remain relatively constant for many years, since the area is accumulated on an ever increasing diameter, the radial increment must decrease. Claims of a constant, high, radial increment in older red spruce in uneven-aged stands by McLaughlin and others (1987) cannot be substantiated. Data from Murphy (1917) and from Oosting and Billings (1951) indicate that growth in diameter is independent of age in their samples but not that it is independent of stand basal area development or that it can be constant at the rate of 2 to 4 mm per year (the radial increment rate of 1 to 2 mm per year) achieved by most vigorously growing red spruce. Tolerant trees like red spruce grow at rates dependent on their physiological age, not their chronological age (Hyink and Zedaker 1987). Although red spruce has demonstrated the ability to continue growing (at rates approaching 0.5 mm mean radial increment) when stressed by competition or by excessive respiratory burdens, it could not be expected to maintain its mean maximum growth rate indefinitely.

Conclusions

Based on the data collected in this project to date, no link between pollution and stand conditions can be made. Other than the Fraser fir mortality associated with the balsam woolly adelgid, the current stand conditions of the Southern Appalachian spruce-fir forest, unlike the Northern Appalachians, give no indication that abnormal events are occurring. Basal area development is consistent with expectations based on site quality and time since

Table 7.--Comparison of site index values to actual and and predicted stand basal area based on age of stand for Mt. Rogers NRA and Black Mountains

Elevation	Stand age[a]	Site Index[b]	Myer's Predicted BA[c]	Actual Stand BA[c]	% Crown Class 1[d]
		Mt. Rogers NRA			
5000	40-60	43	35-40	36-40	87
5500	75-80	40	45-47	35-45	90
		Black Mountains			
5000	105-125	57	60-63	40-63	79
5500	75-90	52	55-57	46-47	89
6000	50-75	47	40-50	28-32[e]	89
6500	55-75	40	40-45	20-38[f]	93

[a] Stand age is based on spruce and fir dominants and codominants.

[b] Site index is based on spruce and derived from curves in Meyer (1929).

[c] Stand total live basal area (m^2/ha).

[d] Percent of spruce that have crowns 90-100% intact.

[e] Dead fir basal area at 6000 ft: 4-10 m^2/ha.

[f] Dead fir basal area at 6500 ft: 16-25 m^2ha.

disturbance. Spruce crown condition seems better linked to the proximity of the stand density to carrying capacity than to potential level of pollution exposure (elevation). It is possible that the fir may have been predisposed to adelgid damage as a result of anthropogenic stress although the insect was present, and caused significant mortality, prior to 1960. Also, temporary natural disturbance effects cannot be discounted. While persistent insect infestations and large scale logging impacts are long-term and continuous, events such as drought and ice storms can temporarily mask long term growth trends. Severe droughts during the 1986 and 1987 growing seasons, and a very damaging ice storm in the winter of 1986-87 must be considered in the evaluation of future growth, vigor and mortality.

Definitive proof of a pollution caused decline cannot be obtained by data collected solely within this project. Information on current stand and tree condition, stand and tree growth and mortality from repeated measures, soils and site quality, stand history and pollution exposure will be needed to provide any link to the atmospheric deposition of pollutants. Actual levels of pollution exposure over the stratification variables used in this study and detailed soil nutrient data must be obtained as a first step in this process. If abnormalities (judged as such in relation to normal expectations and their variance) in stand development occur, and they are correlated to extremes in soil condition or pollution deposition, they will provide some valuable field evidence that pollution may be causing a decline. The significance of that decline can only be judged in light of other supporting evidence from laboratory and growth chamber work and the policy makers' definition of the term significant.

Acknowledgments

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Interactions of Spruce-Fir Pathogens, Insects, and Ectomycorrhizae on the Etiology and Epidemiology of Boreal Montane Forest Decline in the Southern Appalachian Mountains

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Abstract

Dieback and decline of red spruce-Fraser fir ecosystems in the southern Appalachian Mountains has been attributed to deposition of anthropogenic pollutants. In order to address the potential impacts of air pollution on these ecosystems it becomes essential to fully quantify and qualify the presence and impact of insects, pathogens and the essential root-fungus ectomycorrhizal relationships. Not until a thorough assessment of biotic impacts is made can reasonable cause and effect etiologies for decline be attributed to man-made pollution. Visual disease and insect assessments were made on SARRMC permanent and destructive plots, roots were collected for microbiological studies of pathogens and ectomycorrhizae. SARRMC destructively sampled plots underwent intensive examination for significant pathogenesis. Laboratory studies were initiated to identify and prove pathogenicity of root microorganisms and spruce/fir ectomycorrhizal identification and syntheses were attempted for the first time. The results of these studies indicated a distinct lack of biotic interactions involved in the observed decline phenomenon. With the exception of Balsam Wooly Adelgid (BWA) damage to Fraser fir, no significant insect infestations were observed on either fir or spruce. Due to the lack of gross pathology observed in forest decline areas; investigations were initiated to assess the potential incidence and impact of virus, mycoplasma, rickettsia and xylem-limited bacteria on the spruce/fir ecosystem. Initial results are negative. Pioneering work on the quantification and identification of spruce/fir root pathogens and ectomycorrhizal symbionts is continuing at this time and will require additional investigation to produce statistically valid information. A technique developed during these studies that enables pure-culture synthesis of spruce/fir ectomycorrhizae in axenic culture will allow for a more complete understanding of incidence and vigor of these symbionts. At the present time it may be concluded that with the exception of BWA there appears to be few if any significant biotic etiological agents adversely affecting Spruce-fir ecosystems in the Southern Appalachian Mountains.

Introduction

Dieback and decline of red spruce-Fraser fir ecosystems in the southern Appalachian Mountains have been attributed to deposition of atmospheric pollutants. In order to address the potential impact of anthropogenic stress it will be essential to fully qualify and quantify the presence and impact of pathogens, insects and the essential root-fungus ectomycorrhizal relationships. It is not until a thorough assessment of the presence, magnitude and vigor of the above biota are made that reasonable cause and effect etiologies involving the impact of air pollutants can be made. This project has conducted pioneering research addressing first, the development of techniques for the field and laboratory assessment of fungal and nematode pathogens, insects and ectomycorrhizae. Following the development of these techniques surveys were initiated in the SARRMC permanent and ancillary plots to address the presence and impact of these biota. Provision of a scientifically valid, statistically accurate assessment of these pathogens and pests is the ultimate goal of this research.

It cannot be overemphasized that an ecosystem level study is by its nature complex and highly integrated. Damage to spruce and fir trees in the southern Appalachian Mountains has caused considerable public alarm. Other than studies on the Balsam Wooly Adelgid (BWA) little is known about the incidence and impact of insects and diseases on southern Appalachian spruce-fir ecosystems. Due to reports of anthropogenic pollution causing tree decline in Central Europe and the northeastern U.S., much attention has been focused on the potential for similar etiological agents being responsible for forest decline in the south. The pest-pathogen component of the SARRMC Spruce-fir Ecosystems study project is paramount to the comprehensive understanding of "damage" to these forests. If it is determined that significant ecosystem pertubation is attributable to natural biotic processes, justification for a de-emphasis of pollution research may be suggested; however, the converse of this scenario should help to focus national research initiatives towards increased attention to atmospheric deposition research.

The deterioration of fine roots is one of many hypotheses proposed to explain the decline of trees in the eastern US and Central Europe. Possible causal agents responsible for changes in fine root status include soil acidification, heavy metal deposition, pathogens, insects and nematodes.

Little quantitative data are available to support a possible relationship between fine root status and forest decline. Livingston and Blaschke (1984) reported up to three times more ectomycorrhizae from less symptomatic red spruce in Bavaria. Data were obtained based on quantification of ectomycorrhizae from soil cores removed from the base of individual trees (90-130 years old) from two decline classes.

Sequential core sampling is commonly used to quantify ectomycorrhizae and is acceptable for most purposes. This method has been employed to describe abundance of ectomycorrhizae and distribution in soil profiles. Harvey, et al., (1976) determined that 95% of active ectomycorrhizae were associated with the organic fraction (usually the upper 15 cm of soil). Menge, et al., (1977) characterized morphotypes of loblolly pine in 11-year-old plantations using soil core sampling

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techniques. Core sampling is less desirable, however, when assessment of ectomycorrhizae is needed on an individual tree basis; alternative sampling techniques such as root excavation may be necessary.

The objective of this study were 1) to describe ectomycorrhizae as morphotypes, because little is known about species of fungi forming ectomycorrhizae with red spruce, and 2) to develop sampling techniques that are biologically and statistically valid, for future investigations of red spruce fine roots.

Materials and Methods

Five hypotheses are being addressed in these studies:

1. There is a physical decline of spruce and fir forests in the southern Appalachian Mountains.
2. This decline is attributable to "natural" biotic factors, i.e. fungi, nematodes, bacteria, virus, mycoplasma and insects.
3. Atmospheric deposition is changing the natural balance of phylloplane and rhizosphere microbiota by either favoring or inhibiting phytopathogenic phenomena.
4. Species of fungi forming ectomycorrhizae with red spruce roots does not vary within a single root system and among root systems for all individuals located within plots.
5. The numbers of ectomycorrhizal tips per unit length of root is similar among all individuals regardless of tree decline rating.

These hypotheses are being addressed in the following manner: Locate SARRMC Plot via written directions as provided by VPI and SU Field Crew (Black Mountain, VA Balsams) and NPS Field Crew (Clingman's Dome).

Upon location of the plot, the general stand condition and plot orientation were noted. These factors influenced our decision whether to sample the plot. If the number of spruce and fir stems were inadequate to produce a statistically valid sample the plot was abandoned. Actual numbers varied from plot to plot, but in general the higher elevations afforded sampling of at least 3 spruce and 3 fir, while at lower elevations, at least 3 spruce were sampled.

Upon the decision to sample a plot, the elevation and aspect was measured for the stand. There were not significant departures from our measurements compared to those provided with plot directions. Other pertinent information including Plot Name (general geographical area), Plot Numbers, Date, and Reference Stake, was recorded.

The chosen Reference Stake must be the downslope corner of the Permanent Plot adjacent to the Ancillary Plot (Fig. 1). The stake number (VPI) or color (NPS) was recorded.

Sample trees must be Dominant or Co-dominant Spruce or Fir, with root systems not extending into Buffer Strip (3 meters wide) (Fig. 1). Initially, trees were to be selected from within the Ancillary Plot. Many times though, inadequate numbers of trees were present in the Ancillary Plot. Thus the Ancillary Plot design was amended such that more trees in the Permanent Plot vicinity could be sampled. An effort was made to select trees throughout the entire sample area.

Once selected, trees were located with respect to the reference stake. Slope distance (to the nearest 0.5m) and azimuth (to the nearest degree) were measured and recorded. Compass declination was set at zero.

From the uphill side of the tree, the Diameter at Breast Height (DBH) was determined. The point is 4.5 ft. or 1.37 m from ground level. The DBH was measured and recorded. A circular metal tag was nailed into the tree at DBH and proximal to the reference stake. The metal tag was labeled (using a die set) with the following information:
1) Mountain: B = Black; R = Rogers; S = Smokies.
2) Plot Number.
3) Tree Number.

Trees were then assessed for Dieback, Decline (CA), Decline (F). Dieback was assessed on a 10 point scale; that is 1 = 0 to 10%, 2 = 11 to 20%, 3 = 21 to 30%, etc. Generally, this estimate expresses the amount of dead or defoliated crown. On a rare occasion, an individual with massive lateral dieback in the upper portion of the crown was given a rating other than a 1. Decline (F) was assessed by counting annual needle retention of the non-shaded, live crown. Fir was assumed healthy with at least 5 years of needles, and spruce with at least 6 years. A 4 - point scale was incorporated: Fir, 1 = 5 to 4 years, 2 = 4 to 3 years, 3 = 3 to 2 years, 4 = 2 to 1 year; Spruce, 1 = 6 to 5 years, 2 = 5 to 4 years, 3 = 4 to 3 years, 4 = 3 to 2 years.

Decline (CA) was assessed on a 4 point scale: 1 = 0 to 10%, 2 = 11 to 50%, 3 = 51 to 90%, 4 = 91 to 100%. This is an estimate of the amount of defoliated crown (usually the inner crown) as a percent of the total non-shaded crown. Note that this decline rating scheme was difficult to learn and use.

The presence of excessive necrotic and chlorotic foliage was noted and recorded. All fir stems were carefully inspected for the signs of infestations of the Balsam Wooly Adelgid, and a host of other biotic diseases and insects (Tables 1 and 2).

Finally, root excavations were performed on each tree. Individual samples were collected from the four principle compass points (N, S, E, W) from the base of the stem. Root material must (if possible) include tertiary and fine feeder roots, with a quantity great enough to fill a quart size ziploc freezer bag. Individual paper tags, showing plot number, tree number and direction, were placed into bags with the roots. As quickly as possible, sample bags were placed in ice filled coolers. Within 72 hours, bags were transported to the laboratory for further analysis.

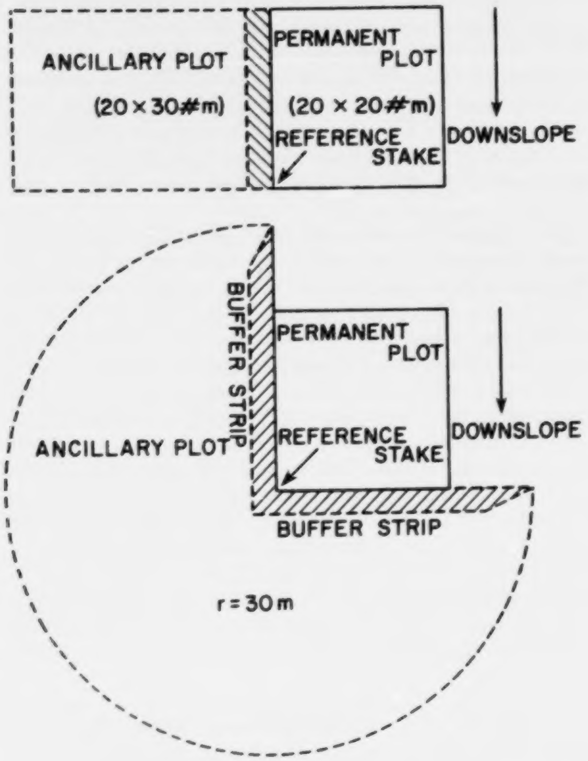

Figure 1.--Sampling plot design.

Commencing in late August 1985 a field crew from NC State University began collecting root samples from SARRMC permanent plots. These plots were established on Mt. Rogers, Mt. Mitchell (Black Mountains), and Clingmans Dome (GSMNP) by investigators from VPI and SU, Principal Investigator S. Zedaker and from the National Park Service, Principal Investigator Peter White. Although plot designs differed from these two research teams, they had no effect on root analysis and data collection methodologies. Each plot consisted of the establishment of a permanent plot 10 meters x 10 meters on a side. Initially ancillary plots were established on either one of the two sides of the permanent plot consisting of a 10 meter x 20 meter section. However, following a preliminary reconnaissance of ancillary plots it was determined that too few trees existed within these plots for pathogen, insect and root sampling methodologies, therefore it was determined that from the down slope corner stake of each permanent plot a 30 meter arc was constructed which encompassed ¾ of a circle around the plot avoiding any uphill trees to avoid disturbance that might effect permanent plot ecology.

Table 1.--Fraser fir insect and disease survey

1.	Balsam wooly adelgid	ND/D/M
2.	Balsam twig aphid	R
3.	Balsam gall midge	R
4.	Spruce budworm	ND
5.	Sawflies	ND
6.	Spittlebugs	R
7.	Needle scale	ND
8.	Spider mites	R
1.	Needle rusts	ND
2.	Needle cass *(Diplodia* blight)	ND
3.	Witches broom rust	ND
4.	All stem cankers	ND
5.	Root and butt rot *(Armillaria mellea)*	ND
6.	Heart rot conks	ND

ND = not detected; C = common; R = rare; D = damage; M = mortality.

Table 2.--Red spruce Insect and Disease Survey

1.	Eastern spruce gall aphid	ND
2.	Spruce needle miner	R
3.	Spruce budworm	ND
4.	Sawflies	R(?)
5.	Needle scale	R
6.	Spittlebugs	R
7.	Bagworms	ND
1.	Rhizosphaera needle cast	ND
2.	Cytospora canker	ND
3.	Stem cankers	ND
4.	*Armillaria mellea*	ND
5.	Root and butt rots	ND
6.	Needle rusts	ND
7.	Heart rot conks	ND

ND = not detected; C = common; R = rare; D = damage; M = mortality.

The right hand down slope corner stake from each permanent plot was chosen as a reference for the locating of selected trees. Five Fraser fir and five red spruce individuals were chosen within each ancillary plot. Individual tree selection was governed by the following criteria.

1. Dominant and codominant spruce and fir, 5 from each species.
2. Trees must be within 30 meters of a reference stake, with care taken to insure consistent site and stand characteristics i.e. slope, slope position and aspect, and trees preferably in areas that posed no threat of disturbance to permanent plots, since slight to moderate destructive sampling was implied during the pathogen survey.
3. Each individually chosen tree was flagged and mapped with respect to azimuth and slope difference from the reference stake and mapped accordingly.
4. Individual tree data including DBH, dieback and decline ratings, any detected abnormalities i.e. broke tops, incidence of balsam wooly adelgid or all other insects, were recorded and numbered, aluminum tags were nailed to each tree at DBH as permanent markers of the trees on respective plots.
5. At the four cardinal compass points i.e. North, East, South and West around each tree, primary and feeder roots were excavated back to the main tree ball root and bagged separately by compass bearing, with any abnormalities or obvious pathogens noted. Before bagging each root segment was observed for the presence of galls, cankers, or any other visible signs of biotic infestation. Each individual root segment that was collected approximately 1.5 meters from the bole of each tree had to be excavated all the way from the bole to the site of feeder root collection; a great deal of time and effort is necessary to accomplish this task. With consideration to the trees location i.e. slope position, presence of slash etc., as many as 4 hours were applied on each individual tree to collect root samples and carefully analyze tree conditions.
6. Upon excision, root samples which were individually placed in plastic bags, and each site was carefully reestablished by recovering damaged area with surface litter and slash. Root samples were transported in ice chests to the NCSU Forest Pathology Laboratory and held to up to 2 wks in cold storage (4 F) to retard decomposition of root tissues.
7. Once in the laboratory individual bags of roots were washed under sterile distilled water to remove loose mineral soil and organic debris.
8. A sample from each root segment was then randomly separated into three sub samples 1) short feeder roots were placed in a preservative (FPP) for future analysis and quantification and ectomycorrhizal symbionts. 2) segments of tertiary and feeder roots were directly plated out onto 5 antibiotic culturing media to identify pathogens. 3) the remainder of the sample usually more than 50% of the total, was oven dried at 70 C and transported to the laboratory of Dr. Carol Wells and Dr. Wayne Robarge for chemical and nutrient analysis.

Root Pathogen Ectomycorrhizal and Insect Materials and Methods

During the 1985 and 1986 field seasons a total of 105 plots were samples for pathogens ectomycorrhiza and insects. Following the washing of the SARRMC root samples; fresh materials were rapidly isolated onto 3 antibiotic media consisting of malt-agar, potato dextrose agar, and water agar differentially ammended with the antibiotic penicillin, PCNB and hymexizol. The remainder of each fresh root sample was perserved in a solution of 90% propanal, 5% formalin, and 5% glacial acidic acid. Prior testing of this solution indicated that roots and ectomycorrhizae do not change in color or other morphological features to later be utilized in the quantificaiton of these biotic phenomenon.

Initial microbial isolations made on the five antibiotic media were made. Consisting of 1) Triple P., 2) PCNB-Agar, 3) Nash and Snyders, 4) PCH, and 5) Acid-PDA. Fungi growing out from roots in pure culture were subcultured onto tubes of antiboitic media after approximately 5 days on petri plates. Further subculturing of all isolated fungi have yielded, at this time, over 3,000 pure culture tubes of fungi from spruce and fir roots. At the present time attempts are being made utilizing different light and temperature chambers to induce sporulation of interesting fungi, particularly those from the family Basidiomycete. Initial analysis of fungi indicate that numerous species of Phythium are found from the internal portions of effected short roots, it has yet to be determined whether these fungi are acting as primary pathogens or simply secondary infections on stressed roots. If identifiable fungal pathogens are isolated in pure culture attempts of inoculating fungi to healthy spruce and fir roots under greenhouse conditions will be initiated to try to complete Koch's postulates of pathogenicity.

Ectomycorrhiza. Mycorrhizal associations and plant diseases of feeder roots have an important similarity. Both are types of parasitism intimately involved in the succulent fine feeder roots of their tree hosts. During the synthesis of the mycorrhiza the host responds physiology to the infection and the fungal symbionts undergo certain transformation. Studies at NCSU have demonstrated that highly ectomycorrhizal individuals of the genus *Pinus* in the field are much more resistant to feeder root pathogens than are poorly mycorrhizal or a mycorrhizal trees. In addition experiments with loblolly pine by Shafer et al., 1984, and Meier et al. 1985 (unpub.) showed that mycorrhizal fungi may be significantly damaged with simulated acid rain regimes at or below 4.0. This would be an acid rain level considered ambient for the mountains of the southern Appalachians.

SARRMC Ectomycorrhizae Sampling Procedure

The choice of a sampling technique is dictated by the size and location of plants under study. Entire root systems can be examined on seedlings however, this is impossible for larger plants. The number and size of samples root or soil required for valid statistical and biological comparisons can vary considerably. Most often this is determined for each study as is presently being done by the Spruce Fir cooperative. Initially a 5 centimeter diameter soil core technique was employed, but found to be inadequate for spruce fir ecosystems as each sample is a combination of both spruce and fir roots with undetermined individual trees being identified for the samples. It was hence determined that the only adequate way to get valid root samples from a known tree at a known distance from that tree was to fully excavate the boles at the north, east, south and west directions of each tree and collect a representative root mass at approximately 1.5 meters from the tree itself. In this particular study which involved numerous trees with large masses of roots, the number of roots to be examined precluded the counting of ectomycorrhiza on all roots. In such cases roots are randomly selected from the seedling in some manner and a number of ectomycorrhiza are counted. The random selection of a predetermined number of root segments from each root mass was undertaken i.e. Ten-10 centimeter segments. The results of this quantification procedure will be expressed as the number of ectomycorrhiza per unit length of root and the percent of short root ectomycorrhizal. In addition it was determined that this research program required the quantification technique that more accurately reflected the function of the ectomycorrhizal tips. Therefore it was determined that our study would quantify ectomycorrhiza by counting the number of ectomycorrhizal tips and hence calculating the average surface area of each tip to determine functional root mass. These results will be expressed as the number of living or active ectomycorrhizal tips per unit volume of soil, surface area of the ectomycorrhiza per unit volume of soil, number of living ectomycorrhizal tips per soil fraction, and the number of living ectomycorrhizal tips per unit weight of soil.

Another major objective of our study is to determine differences in the speciation of the ectomycorrhizal symbionts both among and between plots and to determine upon repeated sampling over a series of 3 years whether ectomycorrhizal speciation is changing possibly due to changes in loading from atmoshperic deposition. To accomplish this subsamples of ectomycorrhizal short roots will be quantified by morphotype. Morpho- typing is necessary to characterize ectomycorrhiza because we do not know the species of fungi involved in these relationships. Although, the Postdoctoral Fellow working on this project at this time is employing advanced techniques to isolate individual ectomycorrhizal fungi and to determine both genera and species, these fungi are exceptionally difficulty to isolate and will not produce sporocarps on artificial media. As a result the ectomycorrhiza are grouped at this time according to easily recognized and repeated characteristics, such as color, texture, shape and size. In addition a comprehensive photographic record of our ectomycorrhizal types is being kept so as to insure archiving of our data in future years. At the present time our sampling strategy is incorporating the following methods: Ten short root segments are randomly removed at a length of 10 centimeters each from 4 locations on each tree at 1.5 meters from the bole x 10 trees per plot. Due to the fact that 35 plots were visited for sampling during the 1985 field season a total of 4,000 centimeters of root per plot were taken and being quantified thus necessitating the fact that 1,400 meters of root are being quantified for ectomycorrhiza using the above techniques on 35 samples plots. Following the quantification of these data, principal component and other multi variant analysis techniques will be employed to determine significant relationships among tree growth and condition parameters, decline statistics, the formation and speciation of ectomycorrhiza, geograhic location of the stands and other factors to help determine the spectrum of ectomycorrhizal effects in the southern Appalachian Mountains.

In 1984 and 1985, soil cores and root samples were randomly removed from plots established to study forest decline in the Southern Appalachians. Samples were used to describe morphotypes of ectomycorrhizae and to determine the distribution of fine roots in the soil.

In 1985, root samples were removed from two dominant or co-dominant red spruce (Decline Class One) from randomly located permanent plots established to study various aspects of forest decline. Two to ten trees were sampled per plot (23 plots total). (Insufficient numbers of declining red spruce and all firs precluded complete analyses of fine roots with the plots.) Sections of long root were excavated from each of four directions (N, S, E, W) per tree. Roots were traced out from large buttress roots and removed by hand. Samples from each direction were maintained and processed separately to determine the variability within a single root system. Roots were washed in tap water and subsamples were removed for tissue analyses and quantification of ectomycorrhizae. Samples used for assessment of fine roots were preserved in a solution or propanol, formalin and glacial acetic acid to prevent deterioration in storage. Roots were quantified as the number of ectomycorrhizal tips per morphotype for each unit length until 20 cm of long root had been counted, per sample. Histological sections were prepared to examine mantle morphology and to verify the presence of a Hartig net.

Data were subjected to linear regression to detect differences in ectomycorrhizae within root systems and among trees and plots and to obtain estimates of variance at the root, tree and plot levels. The variability within individual root systems was unknown, therefore the data were tested to determine if the mean number of ectomycorrhizal tips differed with the direction of sampling. Variance estimates were used to develop predictive equations to determine optimum sample size for further investigations of ectomycorrihizae under similar field conditions. The number of roots, trees and plots can be varied in the equations and used with the estimates of variance to arrive at a confidence interval for the mean number of ectomycorrhizal tips.

Quality Assurance/Quality Control Procedures

Quality assurance and quality control parameters in the biological sciences is almost equivalent to the quality and care exercised by the personnel collecting the said data. The procedures used in this study are costly, lengthy, and time consuming due to the extreme consideration of consistency in our data procurement. This is accomplished by the following 5 points.

1. All personnel are elaborately trained in both field and

laboratory techniques and tested for consistency of observations by blind scoring of samples underneath the microscope, collecting of specimens from the field, and by the assessment of computer generated keys for decline symptomatology.

2. Each field technician is carefully trained in the mapping and excavation procedures for the procurement of root tissue. A point that is strictly emphasized is the rapid transfer of specimens taken from the field to ice chests and their return to NCSU Forest Pathology Laboratory for processing. This usually entails from 1 to 3 days from removal to laboratory delivery.
3. Once specimens are received in the lab they are immediately processed by 4 technicians for isolation of pathogens, segments for chemical and nutrient analysis and fixing for ectomycorrhizal quantification.
4. All procured reagents, chemicals and antibiotics are considered reagent grade and are mixed according to strict and previously published procedures on media preparation in our sterile laboratory procedures.
5. Through the procurement of our dissecting microscope and photomicrography unit from last years U.S. Forests Service grant, a comprehensive photographic record of all root specimens is made for the purpose of being able to monitor consistency of quantifications and such subjective determinents as shape, texture and color. Due to the potential problems of the subjective nature of these determinations it was decided that 1 Ph.D. candidate would be responsible for all visual determination on the over 1,400 meters of root to be determined from the 1985 field collections. As previously stated all points along this quantification are photo documented for the purpose of repeatability with potentially different professional personnel in the future.

I. Mycorrhizal synthesis (unless otherwise stated, media and techniques are as described in Schenck, 1982)
   A. Nonaseptic: Twelve isolates of 10 different fungi each reported to form ectomycorrhizae with tree species other than red spruce were obtained from other researchers. The fungi were *Amanita muscaria, Cenococcum geophilum, Cenococcum graniforme, Corticium bicolor, Hebeloma arenosum, Hebeloma crustuliniforme, Laccaria laccata* (2 isolates), *Pisolithus tinctorius* (2 isolates), *Suillus cothurnatus* and *Thelephora terrestris.*

Syntheses were attempted using the growth pouch technique (Fortin et al, 1983; Piche and Fortin, 1982). Red spruce seedlings grown for 3-4 months in coarse vermiculte were tranferred into flat plastic pouches containing a paper blotter and 15 ml of an inorganic growth solution. During the course of incubation distilled water and a second inorganic solution were added to maintain moisture in the pouches and supply additional nutrients. Approximately 2 weeks after insertion of seedlings, after root growth over the blotter surface had begun, 3 mycelial plugs were inserted into each pouch. Plugs had been cut from margins of actively growing colonies on MMN medium and placed on the surface of the medium until hyphal regeneration had begun. Throughout an additional 8-12 weeks incubation, during which both shoot and root growth continued for most trees, the growth of mycelium after the blotter surface and mantle formation were observed. Trees were then removed from pouches, the colors, textures and, morphology of mantles recorded, and samples removed for microscopic study. Suspected mycorrhizal rootlets were examined microscopically in lactophenol and cotton blue or fixed in formalin-acetic-acid alcohol, dehydrated through an ethanol tertiary butyl alcohol series, and embedded in Paraplast for later microscopic study.

B. Aseptic: An attempt to synthesize mycorrhizae in large test tubes using the same isolates mentioned above and additional isolates from fruiting bodies collected in spruce-fir or spruce-hardwood stands in the vicinity of Mt. Mitchell, NC is also underway. The field isolates were obtained by plating bits of cap or stripe tissue onto MMN medium ammended with benomyl and chloramphenicol to reduce contamination. Fruiting bodies yielding isolates were identified as *Boletus badeus, Laccaria proxima, Lactarius sordidus, Lactarius vinaceorufesceus,* and *Paxillus involatus.*

Aseptically produced red spruce germinants were transferred to capped, autoclaved 220 x 38 mm test tubes containing a vermiculite-peat mixture and MMN nutrient solution. Inoculum plugs were transferred to the same tubes two weeks later. Incubation of these tubes is continuing.

II. Root cultures

Hundreds of pure cultures maintained on potato dextrose aga in test tube slants have been sorted into groups based on gross morphological characteristics (color, texture, etc.). In a continuing process, tubes are randomly selected from these groups for further examination. Isolates are grown on PDA in petri dishes to observe colony morphology and slide mounts made to observe hyphae and fruiting structure.

Results

The visual surveys conducted on the SARRMC plots has yielded little significant pathology. We were most concerned with a detection of lethal diseases such as *Cytospora kunzeii,* a canker on red spruce, and *Armellaria mellea* a root pathogen of both spruce and fir. All attempts to detect or isolate these pathogens failed. Tables 1 and 2 summarize the list of insects and diseases that were (or in more cases were not) detected in our survey. All insects of concern to both spruce and fir were either not detected or were of such low population levels, that they were deemed to be insignificant and not causal in the decline sypmtoms observed. The only exception to this was the presence of damage by the Balsam Wooly Adelgid (Table 3); however, due to an extremely cold temperature exposure (-34°F) recorded throughout the southern Appalachians (Jan. 21, 1985) signs or symptoms of living insects were almost impossible to detect. The population has subsequently (late Summer, 1987) made an alarming rebound which will probably require a re-survey on SARRMC Permanent Plots to quantify.

Trees were scored on the basis of physical damage, gouting or the presence of any signs of insect infestation. During surveys up to and including August 1987, Adelgid was not detected on any SARRMC Plot Fraser fir on Mt. Rogers, on 39% of the fir in the Black Mountains and 27% of the trees on Clingmans Dome (GSMNP). It could be assumed with a reasonable degree of confidence that the majority of standing dead fir have succumbed to at least in part, aphid attack.

Commencing Spring 1987 attempts were made to isolate and identify virus, mycoplasma, rickettsia, and xylem-limited bacteria from each of 20 symptomatic (chlorotic) spruce and fir from Mt. Rogers, Black Mountains, and Smokies. Facilities at the Virology and Electron microscope lab at NCSU were utilized. All results were negative.

Attempts to isolate the pathogenic root fungi - *Heterobasidium annosum*, *Armellaria mellea*, and *Verticicladiella procera* from fine root tissue failed.

The 1984 and 1985 efforts to characterize ectomycorrhizae resulted in the description of ten different morphotypes of red spruce. The morphotypes are described by color, morphology and mantle characteristics. Figures 2-6 show spruce and fir ectomycorrhizal morphotypes. A single morphotype (designated as B) accounted for 68% of the mean number of ectomycorrhizal tips from all samples. Similar observations have been reported in other systems; for example, a single morphotype comprized 93% of all ectomycorrhizae in mature Douglas fir/larch systems (Harvey, et al., 1976). The number of ectomycorrhizal tips per cm long root for each morphotype, the total number of tips per plot and the frequency of the morphotypes for each mountain site are provided in Table 3.

The predictive equations (Table 4) are based on the assumption there is no effect of the direction of sample from individual trees. Data analysis from this study supports this assumption and therefore is valid for results reported here.

Table 3.--Number of ectomycorrhizal tips per cm long root

Plot[a]	Morphotype										Total tips
	BW	G	B	GWF	WTGT	BWT	C	WW	Y	CT	
B32	-	.11	1.28	-	-	-	.83	.17	-	.03	2.42
B33	.01	.74	3.37	.12	.10	-	.30	1.16	-	-	6.16
B34	-	.09	4.27	-	-	-	2.41	.83	-	-	7.60
B48	-	.05	5.67	.04	-	-	.91	.63	-	-	7.30
B50	-	.54	4.51	-	.01	-	.35	1.31	-	-	6.72
B52	-	1.61	4.55	-	-	-	1.53	1.46	-	-	9.15
R4	-	.41	3.88	.29	-	-	2.37	.82	.01	-	7.78
R5	.03	.16	5.87	.02	.05	-	2.66	1.75	.23	.21	10.98
R14	-	.05	4.18	.02	-	-	2.11	.73	-	.23	7.32
R17	.24	1.14	5.93	.45	.05	-	.04	1.04	.03	.04	8.96
R20	-	.38	3.77	-	.01	-	.02	1.73	-	.03	5.94
R22	-	.17	9.36	.005	.04	.07	1.86	.96	.21	.13	12.80
R27	-	.10	7.62	.03	-	-	.14	.10	-	-	7.99
S305	.02	1.25	7.11	.06	.32	-	.11	1.44	-	-	10.31
S306	-	.47	5.01	.23	.24	.004	1.16	.03	-	.21	7.15
S310	-	.53	4.18	-	-	-	.65	1.28	-	.03	6.67
S314	-	.44	5.55	-	-	-	.41	1.78	-	.28	8.46
S317	-	.22	5.73	-	-	-	.40	.34	-	.08	6.77
S332	-	.03	4.37	-	-	-	.77	.73	-	.03	5.93
S340	-	.17	5.07	.16	-	-	.51	.27	-	.005	6.19
S343	-	.11	4.73	.08	.02	-	.33	.19	-	.05	5.51
S345	-	.31	4.84	-	-	-	1.05	.76	-	-	6.96
S351	.01	.44	6.50	-	.02	-	.24	.59	-	.14	7.49

Frequency by mountain

MTN	BW	G	B	GWF	WTGT	BWT	C	WW	Y	CT
B	0.17	1.0	1.0	0.33	0.33	0	1.0	1.0	0	1.0
R	0.29	1.0	1.0	0.86	0.57	0.14	1.0	1.0	0.57	0.71
S	0.20	1.0	1.0	0.40	0.40	0.10	1.0	1.0	0	0.80

[a] Plot or mountain designated as Black Mtns. (B), Mt. Rogers (R), and Smokey Mtns (S).

Table 4.--Predictive equations to determine optimum sample size for assessing ectomycorrhizae of red spruce

Estimating Components of Variance

1. Assume no effect of direction of sampling

Plot $\sigma_r^2 + k_2\sigma_t^2 + k_3\sigma_p^2 = \hat{\sigma}_p^2$

Tree (plot) $\sigma_r^2 + k_1\sigma_t^2 = \hat{\sigma}_t^2$

Root (tree) $\sigma_r^2 = \hat{\sigma}_r^2$

2. Predictive equations for sampling

$$\text{Variance}_{(\text{region})} = \frac{\hat{\sigma}_r^2}{r \cdot t \cdot p} + \frac{\hat{\sigma}_t^2}{t \cdot p} + \frac{\hat{\sigma}_p^2}{p}$$

$$\text{Variance}_{(\text{plot})} = \frac{\hat{\sigma}_r^2}{r \cdot t} + \frac{\hat{\sigma}_t^2}{t}$$

The equations were used to determine optimum sample size over the entire area sampled, and also for individual mountain sites (total of three). Significant differences were detected with respect to numbers of ectomycorrhizal tips among plots and mountain sites. Based on the 1985 data, optimum sampling size for each mountain site is 24 plots, 5 trees per plot and 20 cm of long root from each of four directions for each tree. For this sample size the 95% confidence interval is the mean number of total ectomycorrhizal tips ± 10%. However, to achieve the same level of confidence for individual morphotypes would require at least double the number of plots per mountain site. This is owing to the greater variability in the distribution and frequency of individual morphotypes.

Discussion

The results of the 1985 mycorrhizae study are based on root samples from trees with little evidence of forest decline or dieback. Therefore, the projected sample sizes required for assessment of ectomycorrhizae are probably underestimated. It is possible that greater variation will be found among trees exhibiting symptoms of forest decline.

With respect to the quantification of ectomycorrhizae, the decision to detect differences in total numbers of ectomycorrhizal tips or the number of ectomycorrhizal tips for a given morphotype will effect the sample size required. Overall numbers of tips may be more desirable if the objective of the sampling effort is to relate the status of ectomycorrhizae with tree vigor and healthy. However, if the objective is to detect differences in the species of fungus, then sampling strategies may change as the sampling intensity increases.

Owing to the differences among mountain sites and between plots, further studies should be confined to a particular site of interest and designed to minimize the plot to plot variation by increasing the number of plots sampled. Further, the lack of adequate numbers of trees for each decline class and species suggests reevaluation of plot selection methods. Ecological literature (Green, 1971) supports the random selection of plots within representative areas of interest, rather than selection totally at random within a large, geographic region.

The cost of quantifying ectomycorrhizae should also be considered in sampling strategies. Washing and preserving the long roots from each sample per tree requires approximately 1.5 hours. To minimize error in counting tips by morphotype required the task was assigned to a single observer. Once familiar with the different morphotypes by repeated observations, it required approximately 2 hours to quantify roots from one direction per tree. To quantify ectomycorrhizae according to the recommendations given above will require an estimated 1000 hours or 125 days. The number of additional variables such as tree species or decline class will substantially increase the time required to assess ectomycorrhizae.

In summary - as of this writing (Oct. 87) little if any evidence of significant pathogen infection or insect infestation in SARRMC plots were noted in 1985, 1986, and spring and early summer 1987 with the exception of BWA (Table 5). In addition, an alarming re-emergence of these insects is currently taking place on fir: this phenomenon may necessitate revisiting SARRMC plots that have already been assessed. It must be strongly emphasized that the above data apply **only** to SARRMC Ancillary and destructive plots and may not necessarily reflect conditions throughout the entire Southern Appalachians. It is the recommendation of the author that the "survey mode" of pest-pathogen research in the Southern Appalachians be discontinued, (with the exception of BWA), and replaced by a focused basic research initiative to investigate specific abiotic stress pathosystem dynamics.

Table 5.--Identified insects

1. Balsam Gall Midge - *(Dasineura balsamicola* Lint.) R, B, S.
2. Balsam Twig Aphid - *(Mindarus abietinus* Koch.) R, B, S.
3. Balsam Woolly Aphid, - *(Adelges piceae* Ratz.) B, S.[a]
4. Pine Leaf Chermid, - *(Pineus pinifoliae* Fitch) B.
5. Spruce weevil - *(Hylobius warren* Wood) R. B. S.
6. Pales weevil - *(Hylobius pales)* B.

R = Rogers, B = Black Mtns., S = Smokies.

[a] = Only insect of significance.

Acknowledgments

The author gratefully acknowledges the dedicated assistance of M. Campbell, M. Huster, S. Meier, A. McDaniel, J. Bograd, and K. Reynolds. Their technical assistance and expertise made these studies possible. I also thank T. Nowaczyk for the preparation of this manuscript.

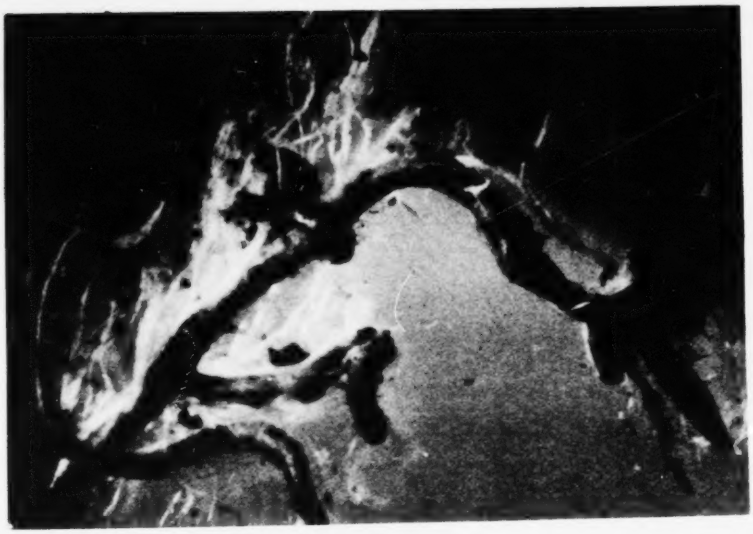

Figure 2.--Fraser fir ectomycorrhizal morphotype--white rhizomorphs (WR).

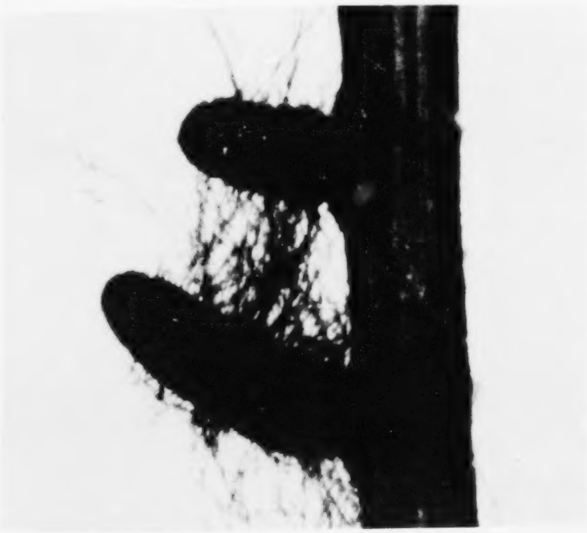

Figure 3.--Fraser fir ectomycorrhizal morphotype--cenococcum.

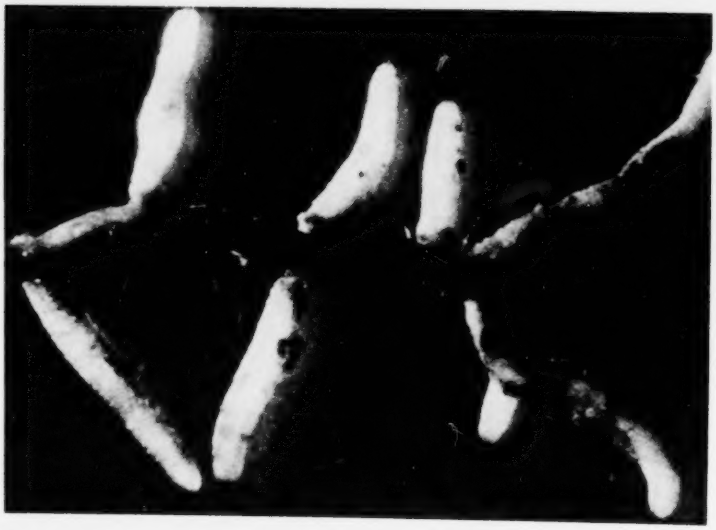

Figure 4.--Red spruce ectomycorrhizal morphotype--white rhizomorphs (W).

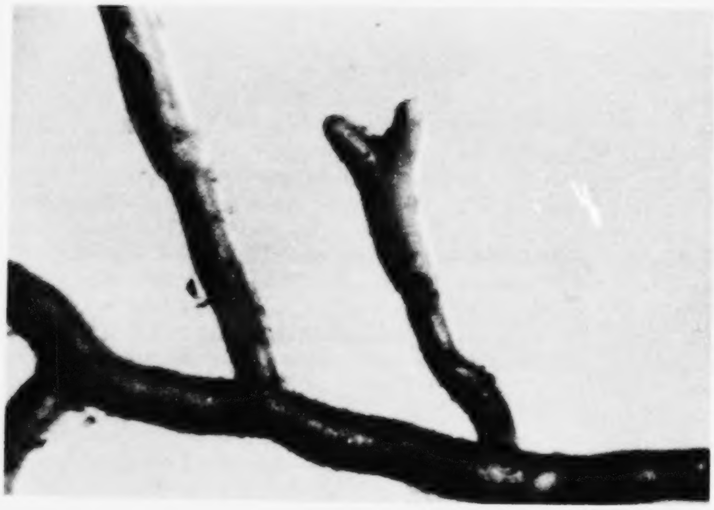

Figure 5.--Red spruce ectomycorrhizal morphotype--tannish brown (TB).

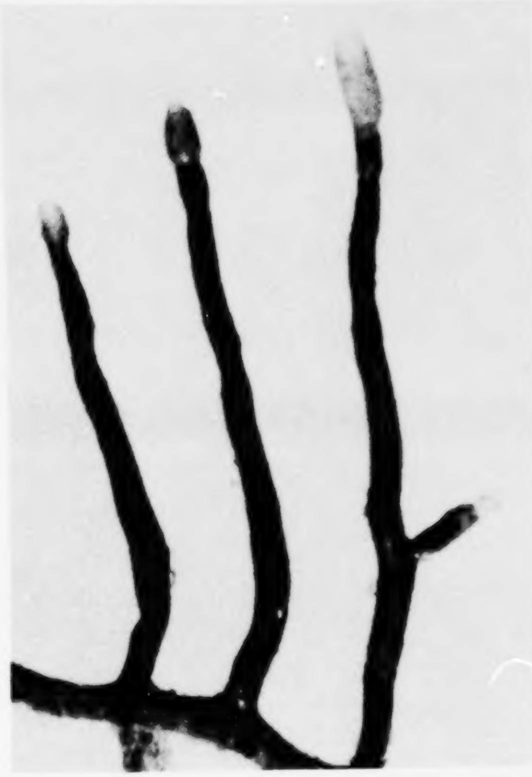

Figure 6.--Red spruce ectomycorrhizal morphotype--white tip (WT).

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Compilation and Interpretation of the Vegetation Data Base and Disturbance History of Southern Appalachian Spruce-Fir

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Abstract

Southern Appalachian spruce-fir forests have been subjected to major disturbances, including logging, blowdowns, slash fires, livestock grazing, and damage by balsam woolly adelgid. Our research has documented disturbance history of these forests from several perspectives: (1) compilation of an annotated research bibliography; (2) compilation of general disturbance histories of three intensive study sites; (3) compilation of specific disturbance histories for permanent plots; and (4) establishment of permanent photomonitoring points in Great Smoky Mountains National Park. Knowledge of historical conditions as well as an understanding of disturbances and their consequences should enable us to better test hypotheses regarding effects of atmospheric pollutants.

Introduction

Southern Appalachian spruce-fir forests have been subjected to major disturbances in the recent past; the most important of these were railroad logging, blowdowns, slash fires, and livestock grazing. These disturbances caused tree mortality and resulted in considerable variation in composition, age, and age-structure of existing stands. These same stands are presently undergoing rapid changes, most dramatically the high mortality of mature Fraser fir caused by balsam woolly adelgid (*Adelges piceae* Ratz). There is also reason for concern over current and future changes caused by air pollution effects on tree growth and physiology (McLaughlin 1985).

Considerable research effort is currently being expended to determine the effects of atmospheric pollutants on the structure and function of southern Appalachian spruce-fir forests. However, present conditions in spruce-fir stands are in part a consequence of past disturbances, and these conditions may affect the ways in which stands react to pollutant stresses. Evidence of decline and mortality cannot be used to implicate the role of pollutant stresses until other, historical causes have been ruled out. Thus it is critical for researchers to have an understanding of the types of disturbances that have affected these forests in the past. We believe that this understanding should be both general, at a regional level, and specific, at the level of the permanent plot or study site. Knowledge of historical disturbances and their consequences should enable us to better test hypotheses regarding effects of atmospheric pollutants.

Objectives

The key question of NAPAP Task Group F with regard to vegetation responses is as follows: What are the effects of atmospheric deposition (wet and dry) on forest structure and function, and how is the response related to edaphic, biotic, and climatologic factors? We have identified three related scientific questions that apply to our work with forest history:

1) Are spruce-fir forest conditions different from those that can be attributed to typical trends and levels of natural variability in forest conditions?

2) What are the effects of man-initiated and natural disturbances on red spruce and fir?

3) What is the effect of forest successional processes on red spruce and fir?

In addressing these questions, we have formulated six primary objectives:

1) to provide a thorough bibliography of research conducted on southern Appalachian spruce-fir forests;

2) to assemble a bibliographic data base referencing results of research conducted on southern Appalachian spruce-fir forests;

3) to compile historical disturbance records for each of the three intensive study sites--Great Smoky Mountains National Park, Mt. Rogers National Recreation Area, and the Black Mountains;

4) to complete a plot specific field investigation that will accompany objective (3), by compiling disturbance records for each of the permanent study plots originally established

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by the Southern Appalachian Research/Resource Management Consortium (SARRMC);

5) to establish a series of permanent photomonitoring points in Great Smoky Mountains National Park for assessment of visible changes in forest conditions; and

6) to synthesize information obtained in the preceding objectives, with emphasis on (a) natural and human impacts on stand structure and stand dynamics in southern Appalachian spruce-fir forests, and (b) the implications of such impacts for testing of hypotheses regarding recent effects of environmental perturbations.

In the following report, we review technical approaches and results, and discuss our work in addressing the above objectives. Results and discussion are provided only for those objectives where work has been completed.

Technical Approaches

Bibliography and Data Base

The starting point for this phase of the project was the bibliography of White and Eagar (1984). Additional references were located by consulting various individuals, examining the bibliographies of known references, scanning issues of journals which carried significant numbers of relevant papers, and examining the catalogues of theses and dissertations at several university libraries. The primary focus was southern Appalachian spruce-fir ecosystems. This topic was interpreted broadly to include autecology, animals, environmental factors, and historical factors, but such areas were searched less exhaustively than ecosystem processes and vegetation. The geographic scope of the bibliography, the southern Appalachians, was taken to be the high mountains of North Carolina, Tennessee, and southern Virginia, roughly corresponding to the range in which Fraser fir is the codominant fir of the spruce-fir forest. Only a small part of the literature on West Virginia, northern Virginia, and areas farther north was included.

References were examined and, if relevant, keywords were assigned and information was entered on standard forms. Keywords were assigned in five categories: subjects addressed, communities covered, geographic scope, type of information, and subjects for which data are presented. Keywords for data were the same as those for subjects addressed. Up to 20 lines of notes were entered for each reference. The focus of the notes was slanted toward information regarding spruce-fir forests. For papers containing data, standard data evaluation forms were used to record up to 6 lines of text on methods and 9 lines on data presented. Additional fields were available to indicate the use of permanent plots, if mentioned, and for the number of samples taken. The information forms were entered into a data base established under the dBASE III + data base management system on an IBM PC. Programs were written in the dBASE III + programming language to access the data.

Historical Records

Written records, historical maps, aerial photographs, and oral history accounts were sought as potential sources of information on the disturbance history of the intensive study sites. In general, published material used ranged from journal articles to newspaper articles. Much reliance, particularly for the Black Mountains, was placed on published and unpublished technical reports. Each of the three sites was visited for field examination of evidence of past disturbances. Our study did not include systematic plot measurements, although plot specific information from disturbance history checklists was compiled.

The usefulness of historical maps was evaluated in a manner similar to that of Pyle (1985). Factors considered were degree of detail shown, reliability of source, and clarity and uniqueness of information. The quality of an historical map was judged in terms of how accurately the information shown could be transferred to United States Geological Survey 7½ minute topographic maps. Low quality maps, i.e., those with no contours, inconsistent scale, or obscure topographic points of reference were used in conjunction with aerial photographs.

Aerial photographs for the years 1939, 1953, 1962, 1963, 1976, 1982, 1983, and 1985, were located and used. Interpretation was based on examination of areas of known disturbance history from which pattern recognition could be developed. Herringbone pattern resulting from cable logging was clearly evident, as were fire boundaries. Young stands, and those appearing to be even aged, were interpreted as resulting from disturbance. Written records, maps, oral histories, or field investigations were consulted for explanations of such stand conditions. Color infra-red aerial photographs were used to determine spruce-fir mortality in Great Smoky Mountains National Park for the years 1976 and 1985. The percent mortality categories and boundaries for 1985 were adapted from the maps produced for SARRMC by the USDA Forest Service Forest Pest Management Group in Doraville, Georgia. Boundaries of disturbed areas shown on maps were frequently identifiable on aerial photographs. Where expedient, boundary placement was copied to USGS 7½ minute topographic maps from an aerial photograph rather than from the original map.

The various sources of information discussed above were synthesized into maps for each intensive study site. It should be understood that our methods did not include focusing the final maps to present a consistent degree of detail. Rather the synthesized maps present what was judged to be the most reliable and most detailed information available for any given point. In some cases, our only sources of information were maps that took a broad brush approach to detail. In other cases, we used the plot specific results of the disturbance history checklist. Thus although the synthesized map product can be quite detailed in part, it must be viewed as essentially broad scale in approach. Where plot specific information is required, the disturbance history checklist developed during this study should be used.

Plot Specific Disturbance Records for SARRMC Intensive Study Sites

During the 1985 field season, the site characterization teams collected field data pertaining to the disturbance history at many of the SARRMC permanent study plots, using a checklist developed by Charlotte Pyle (Appendix A, Pyle and Schafale 1985). The site characterization teams revisited the intensive study plots during the 1986 field season, and most checklists are now completed for the remaining plots.

The disturbance history checklist was designed for convenient use by field crews. Items on the checklist were characteristics easily observed in the field and considered indicative of previous disturbance. Notes on use of the checklist were given to both site characterization plot crews, and a training session was held for the crew working in Mt. Rogers NRA and the Black Mountains. Rather than having a formal training session for the crew working in Great Smoky Mountains National Park, a member of the disturbance history study team, stationed in the park, was available for consultation.

We will analyze the data in the checklists to judge the presence and kinds of historical disturbance in each study plot. Disturbance history determined in this manner will be compared with the disturbance history derived from archival records and maps, as reported by Pyle and Schafale (1985). This analysis will serve as a check on the quality of the stand history data already collected, and will provide a method to refine it. The field disturbance data could also allow analysis of the relationships between various indicators or results of disturbance. All findings regarding the specific history of the study plots will be reported to the other SARRMC investigators so that these findings may be considered in interpretation of their data.

Photomonitoring

During our research in 1985, we found that historical photographs were helpful in indicating changes that have occurred in spruce-fir forests. We established a series of permanently marked photomonitoring points at easily accessible sites, to be used for future assessments of change. Sites were chosen in the Great Smoky Mountains SARRMC intensive study area which offer vistas of spruce-fir forest in which individual trees can be clearly distinguished and examined. Wherever possible, these points were located to correspond with pre-existing photographs located in our historical work. However, the actual number of suitable existing photographs was low. For each photograph, individual trees were numbered and assessed for severity and symptoms of decline. We used both color and black and white film, and, to allow easy repetition of photos in the future, standard 35 mm photographic equipment was employed.

To ensure consistency with the methods of the site characterization teams, we obtained the standard photographs used in training field crew members. We employed the same decline classes and criteria used by these teams (dead tops, thin crowns, etc.). Quality control of our assessments was provided by having independent ratings of the trees. The photographs of the rated trees will be a permanent record for reexamination in the future.

Our decline assessments based on photographs will be tested against those obtained in the field with methods used by the site characterization teams. After numbering the trees to be rated in the photographs, we will locate and assess the same trees on the ground. This procedure will allow us to compare and evaluate our results with those obtained by the site characterization team. We will then have a firm basis for utilizing both current and future photographic records of decline symptomology.

Synthesis

Synthesis will be undertaken by all members of the forest history team, using information available from completion of the preceding objectives. We will attempt to provide program participants with a rational basis for testing of hypotheses regarding environmental impacts. Our approach will be to discuss the main disturbances encountered and the likely consequences for present stand composition, age, and age-structure.

Results

Bibliography and Data Base

The bibliographic data base contains approximately 350 entries. Most of the entries are from the last 2 decades, reflecting the recent increase in scientific research. Among the bibliographic entries, the most frequently addressed topic is the vegetation sample, focused primarily on description of community composition and dominance structure. Several other community-level subjects are also quite frequent. The high frequency of entries related to balsam woolly adelgid, despite the relatively short time span of their presence in the southern Appalachians, is partially a reflection of the intense concern this destructive pest has caused. However, this also results from the nature of the research and publication on these subjects; most are small reports issued after periodic surveys. In terms of geographic coverage, by far the greatest amount of study has focused on the Great Smoky Mountains.

Historical Records

A detailed report of our work with historical records of the three SARRMC intensive study sites has already been presented (Pyle and Schafale 1985), and only highlights will be reviewed here. A total of 20 different kinds of disturbance have affected the study sites. Of these, eight (and possibly nine) occurred prior to European settlement. Five of these, windthrow, native insects and disease, landslides, episodic climatic disturbance (e.g., ice storms), and chronic (i.e., long term) climatic change, can be considered components of the natural disturbance regime. Grazing, logging, slash fires, tree planting, visitor use, blowdowns, and balsam woolly adelgid mortality are common to all three study sites. However, the extent of these disturbances varies among the three sites, as do inherent site conditions in which the disturbances operated. Disturbance maps, as illustrated in Fig. 1, are available for all three SARRMC intensive study sites (Pyle and Schafale 1985).

Photomonitoring

Ten photomonitoring locations have been established in the spruce-fir zone of Great Smoky Mountains National Park. These points are located at overlooks along Rt. 441 and along the road from Newfound Gap to Clingman's Dome. Thirty-five spruce trees have been photographed from these points and rated for decline class and condition, both in the field and on the photographs, by two individuals. Six of the thirty-five trees are also identifiable in historical photographs taken from five to thirty years ago. Of these six trees, three exhibited worsened conditions in the current photographs, two were unchanged, and one had improved. Reports containing detailed instructions for relocation of the photomonitoring points and individual trees, as well as the individual tree photographs and rating information, are being prepared and will be archived in the following locations:
Library at the University of Tennessee, Knoxville
Library at North Carolina State University
Archives in Great Smoky Mountains National Park
Other copies will be held by the Spruce-Fir Cooperative (Dr. C. Eagar) and by three members of our research team (Pyle, White, Wentworth).

Discussion

Bibliography and Data Base

We anticipate that the bibliography and summaries of available data for southern Appalachian spruce-fir forests will be useful tools for NAPAP researchers. It is our hope that these researchers will easily determine which literature is relevant to their interest and which existing data will be useful in their work. The listing of bibliographic entries and data records will be reproduced in its entirety, and the computerized data base will be available for searches based on keywords assigned to each entry.

Historical Records

Disturbances from the time of early settlers through recent invasion by balsam woolly adelgid have affected age class distribution and species composition of southern Appalachian spruce-fir. The current proportions of various age classes and species found in the southern Appalachian spruce-fir ecosystem are believed to be quite different from those of presettlement forests. Lingering effects of past disturbances may explain much of the variation seen in site characterization plots at the three SARRMC intensive study sites. Therefore, analysis of these plots should not be constrained only to consideration of the effects of elevation and aspect. Rather, these plots should be considered representative of the range of stand conditions in the southern Appalachian spruce-fir ecosystem, given existing variation in elevation, aspect, and disturbance history.

It is clear that some currently occurring changes in spruce-fir forests can be attributed to stand dynamics resulting from past disturbances (e.g., reduced vigor or mortality due to competition in young, even-aged stands). Conversely, some changes can be attributed to processes naturally occurring in old-growth stands (e.g., growth slowing in old age). Past disturbance was shown to favor regeneration of Fraser fir, and thus influenced the pattern of subsequent balsam woolly adelgid mortality. In turn the patterns of adelgid mortality can be expected to influence current and future stand conditions. Thus, future studies of southern Appalachian spruce-fir should involve plot stratification that takes into account variation in disturbance histories and resulting stand conditions. Ongoing studies may benefit by stratification of results through use of broad disturbance history categories or by plot-specific characterization of disturbance history.

Conclusion

Southern Appalachian spruce-fir forests have been altered by man in the past and are subject to ongoing natural and man-initiated perturbations that interact with these alterations. Composition and stand structure reflect these effects and are changing as succession proceeds and new disturbances are initiated. Successful interpretation of vegetation response to atmospheric pollutants will depend on our abilities to discern their effects from those associated with other processes and to understand the interaction of pollutant stresses with these processes. When atmospheric deposition is implicated as a cause of forest decline or mortality, hypotheses must be formulated in a manner which permits either rejection of other causes or recognition of their mode of interaction.

Acknowledgments

We are indebted to the following researchers in the Spruce-Fir Cooperative for their assistance with various phases of our research: C.W. Dull, C. Eagar, N.S. Nicholas, and S.M. Zedaker.

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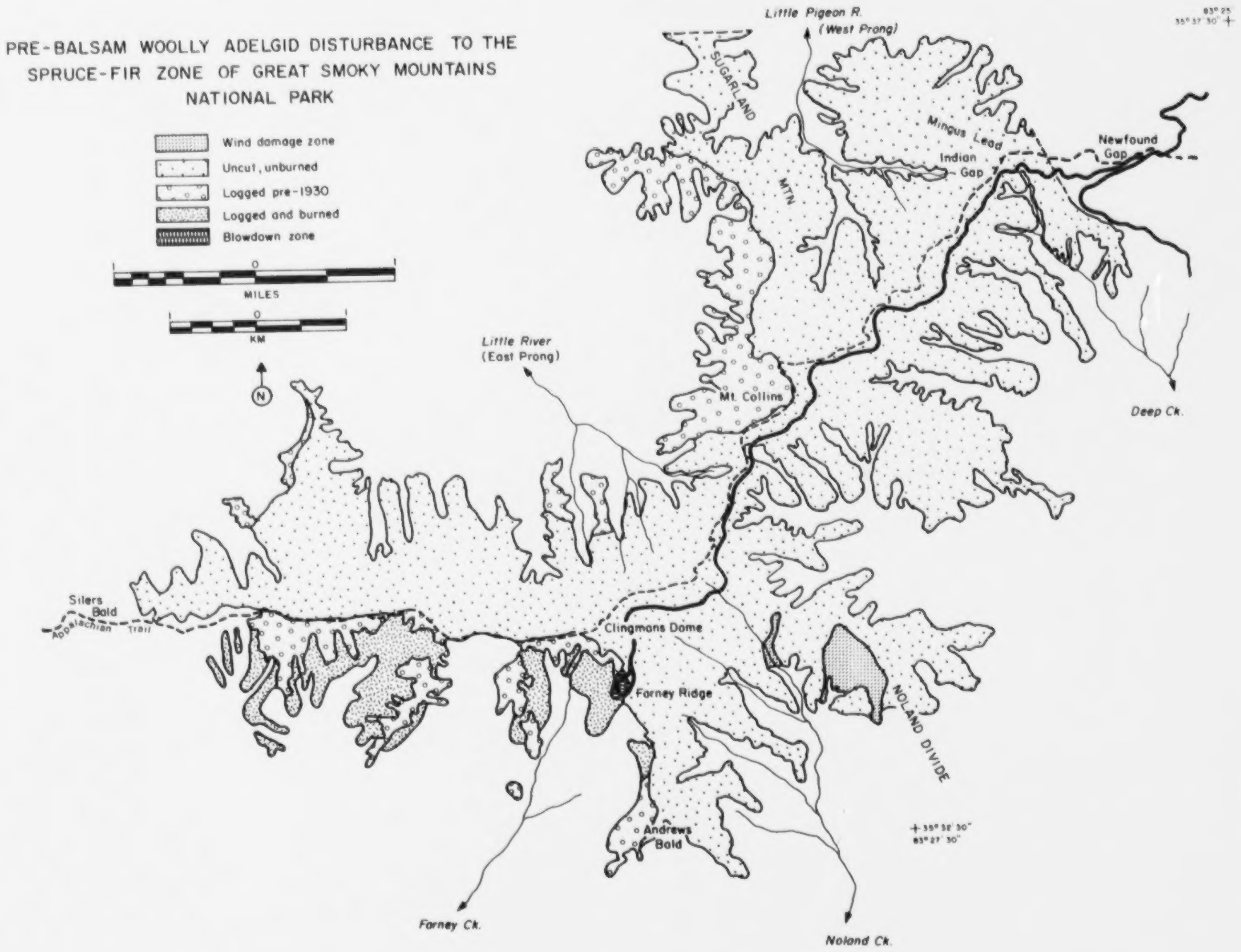
PRE-BALSAM WOOLLY ADELGID DISTURBANCE TO THE SPRUCE-FIR ZONE OF GREAT SMOKY MOUNTAINS NATIONAL PARK
Wind damage zone
Uncut, unburned
Logged pre-1930
Logged and burned
Blowdown zone
0
MILES
0
KM
N
Little Pigeon R. (West Prong)
83° 25
35° 37' 30"
SUGARLAND
MTN
Mingus Lead
Indian Gap
Newfound Gap
Deep Ck.
Little River (East Prong)
Mt. Collins
Silers Bald
Appalachian Trail
Clingmans Dome
Forney Ridge
NOLAND DIVIDE
35° 32' 30"
83° 27' 30"
Andrews Bald
Forney Ck.
Noland Ck.

Figure 1.--Pre-balsam woolly adelgid disturbance to the spruce-fir zone of Great Smoky Mountains National Park.

Modeling Forest Dynamics of the Southern Appalachian Spruce-Fir Ecosystem

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Abstract

We are developing a framework for modeling ecosystem level impacts of air pollution by adapting a forest competition and succession simulation to the southern Appalachian spruce-fir system. Some features of this system that guided restructuring and parameterization of the model include: (1) tolerance of fir and spruce to suppression; (2) optimal growth near the lower altitudinal and latitudinal limits of species ranges; and (3) persistence of the effects of initial conditions reflecting disturbance history. We validated the adapted model using criteria derived from field studies at three southern Appalachian sites. We are using the validated model to project the consequences of hypothesized changes in tree growth, mortality, and reproductive rates that may result from air pollution and other stresses.

Introduction

To address the questions posed by the Forest Response Program -- is there a significant forest damage problem, what are the causal relationships, and what are the dose-response relationships -- the potential effects of acid rain must be expressed in terms of stand and ecosystem attributes that are important to society. At present, simulation of forest competition and succession is the most feasible way to extend studies of physiological processes in individual trees to higher levels of organization. The purpose of our research is to develop a framework for anticipating stand and ecosystem level impacts of air pollution. Here, we report progress in adapting a forest dynamics model to the southern Appalachian spruce-fir ecosystem and in using it to examine the consequences of hypothesized stresses affecting tree growth and mortality.

Modeling Framework

We have proposed an iterative cycle of model development, testing and application (Fig. 1). Policy questions about current and future impacts of air pollution inform the selection of performance standards for the spruce-fir ecosystem. These standards specify the types and magnitudes of ecoysystem change that would be "unacceptable", in terms of the services the spruce-fir system provides to society. The southern Appalachian spruce-fir system is a noncommercial forest, important for recreation and aesthetics, watershed protection, and habitat for other plants and wildlife. We selected these indicators of system performance: (1) density of spruce and fir > 30 cm dbh; (2) density and basal area of spruce, fir, birch, and other species > 10 cm dbh; (3) biomass of spruce, fir, birch, and others > 2.5 cm dbh; and (4) leaf area index. Better indices of watershed protection, now expressed through biomass and leaf area index, are one priority for improvement.

It is difficult, but necessary, to state what levels of these indicators constitute "unacceptable" system behavior, requiring corrective action. It is hard to quantify deviations from conditions that normally vary both in time and space, and it would be poor management to prevent the spruce-fir forest from undergoing changes that are part of its normal dynamics. We chose 30-year and 200-year averages of "normal" behavior to compare with simulated averages of stressed behavior. The 30-year horizon reflects near-term regulatory decisions; the 200-year horizon guards against system responses that may be undetectable in the short term, but difficult to reverse in the long term. To reduce variability and improve discrimination between normal and abnormal conditions, we partitioned the spruce-fir forest into two types, fir-dominated and spruce-dominated; and two age classes, second-growth (most of Mt. Rogers and the Black Mts.) and old-growth (some of the Smokies) (Nicholas et al. 1986). Figure 2 illustrates the extremely high variability of field observations both within and among study sites. "Old-growth" stands in the Smokies include much larger trees and higher biomass than those elsewhere. In addition, recent fir mortality from balsam woolly adelgid attacks may distort our view of "normal" system behavior. For the Smokies and the Black Mountains, where fir mortality due to adelgid attack is especially apparent, we have included dead, as well as live, fir in our estimates of "normal" behavior.

Our assessment of normal behavior from field observations guided selection of criteria for model validation and for stressed system performance. The extreme variability of the field observations dictates that quantitative standards for model validation be supplemented by common sense. Figure 3 shows an example of standards used for model validation and performance of the modified FORET model. We considered both the variability of "normal" behavior and the impact of deviations from normal on system services in assigning standards for "acceptable" and "unacceptable" performance from the stressed ecosystem simulations. We propose that dropping below 80% of the lower bound of "normal" be considered unacceptable for leaf area index and for density, basal area, and biomass of spruce, fir and birch (the dominant canopy species); and less than 30% of normal lower bounds be considered unacceptable for other hardwoods. Figure 4 shows an example of standards for acceptable and unacceptable behavior and of the performance of the simulated ecosystem under several possible stress effects.

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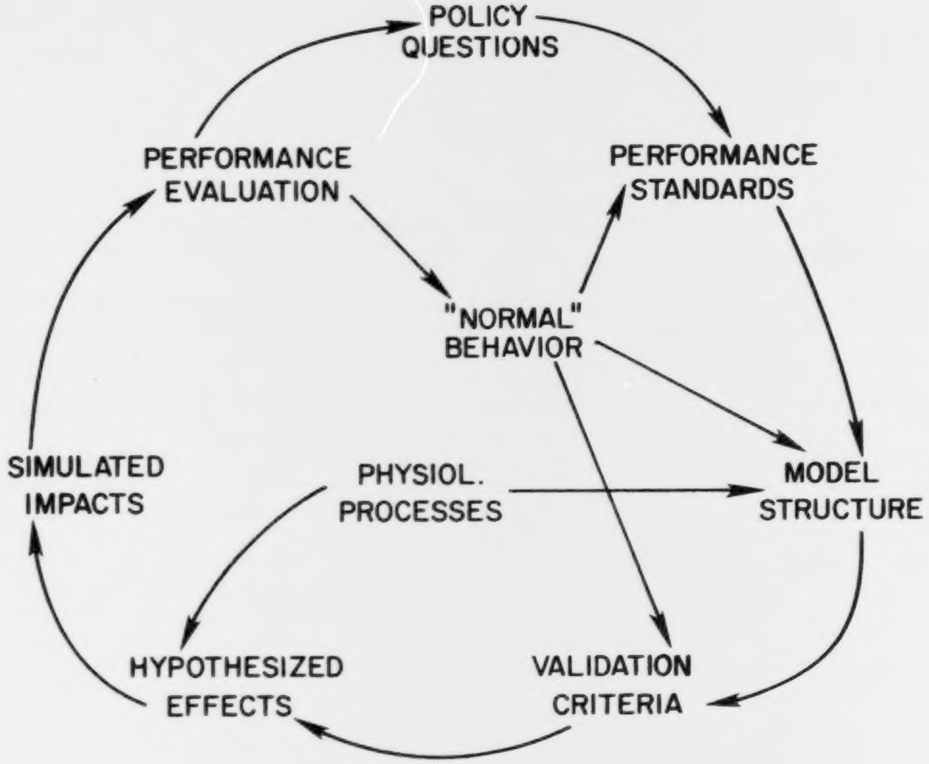
POLICY QUESTIONS
PERFORMANCE STANDARDS
PERFORMANCE EVALUATION
"NORMAL" BEHAVIOR
SIMULATED IMPACTS
PHYSIOL. PROCESSES
MODEL STRUCTURE
HYPOTHESIZED EFFECTS
VALIDATION CRITERIA

Figure 1.--Framework for model development and application.

Additional study of spruce-fir forests and iteration of the modeling framework described here will help refine these standards.

Model Structure

We are adapting the forest competition and succession model FORET (Shugart and West 1977) to synthesize hypotheses about physiological effects of air pollutants, and other stresses, at the stand and ecosystem level. FORET's advantages are: (1) it produces reasonable stand level dynamics from limited input data on silvics and climate (essential for a noncommercial forest with little previous study); (2) it has been adapted to many forest types and environmental conditions with reasonable success (e.g., West et al. 1980); and (3) it is fairly well documented. The basic structure of FORET includes interactions among the environment; a list of individual tree descriptors; physiological processes applied to individual trees; and stand level attributes (Fig. 5). The arrows in Figure 5 show that most processes are influenced by size, age and tree species; by the environment; and by stand characteristics, such as total biomass and shading leaf area. Output from the process models updates individual tree descriptors; these are summed to obtain stand level attributes. One priority for model development is improving the physiological detail of the growth and mortality functions (see Fig. 1).

Model Modification

The process of adapting the model to the southern Appalachian spruce-fir system has revealed places where even the most fundamental knowledge is lacking. One of the model's advantages

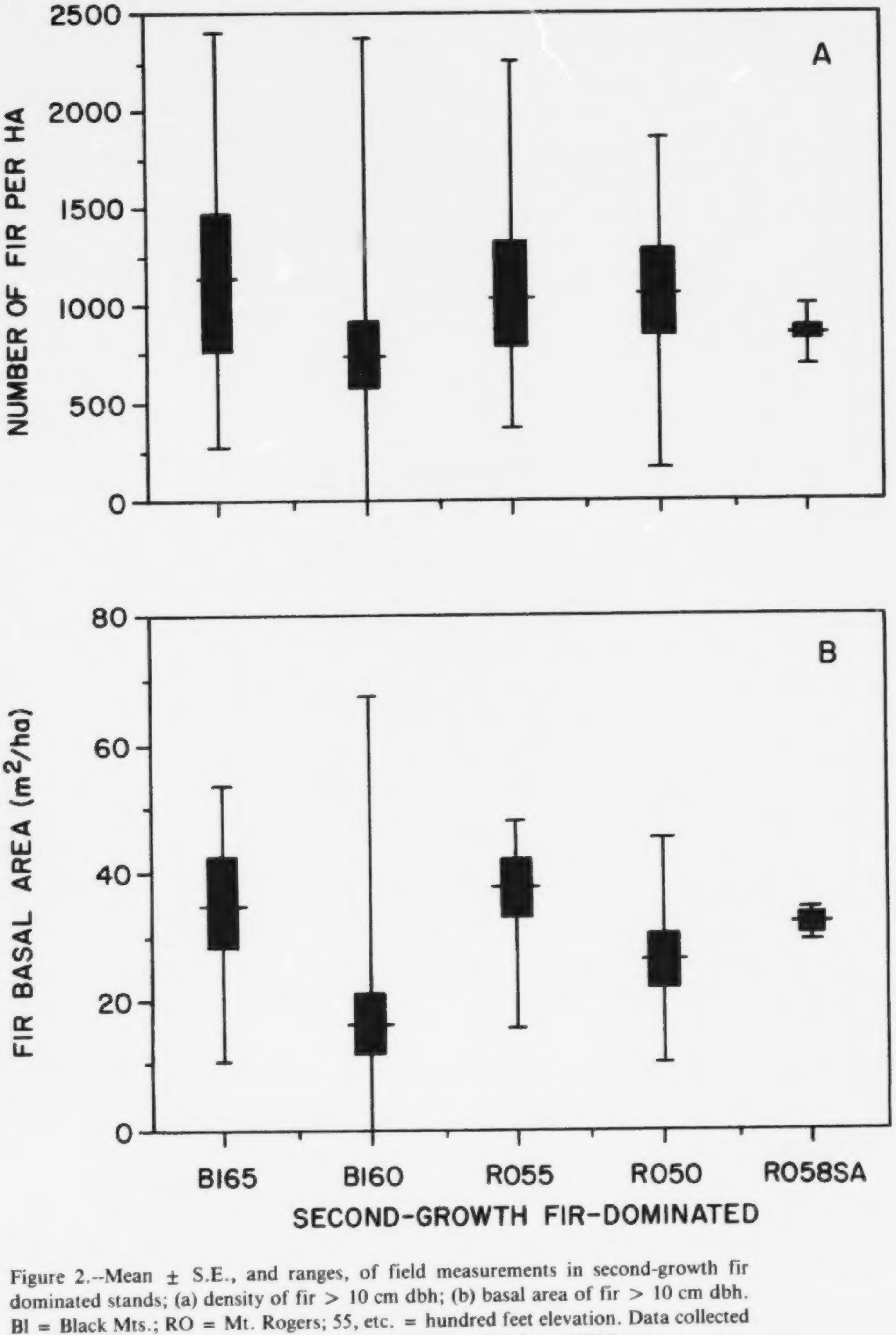

Figure 2.--Mean ± S.E., and ranges, of field measurements in second-growth fir dominated stands; (a) density of fir > 10 cm dbh; (b) basal area of fir > 10 cm dbh. Bl = Black Mts.; RO = Mt. Rogers; 55, etc. = hundred feet elevation. Data collected by Niki Nicholas, Shep Zedaker, VPI; Stephenson and Adams (1984).

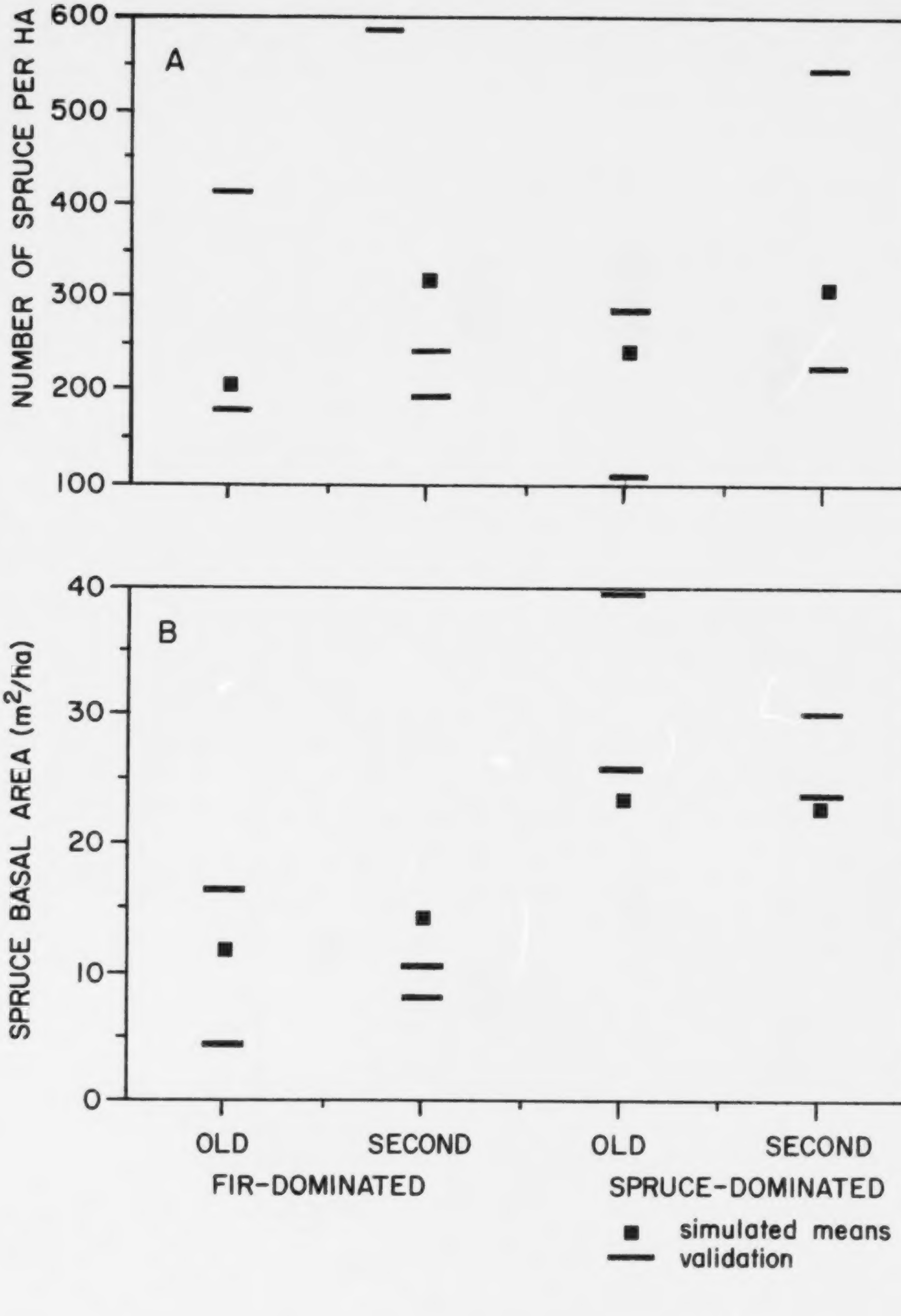

Figure 3.--An example of validation standards and simulated means for the four forest types; (a) number of spruce > 10 cm dbh per ha; (b) basal area of spruce > 10 cm dbh.

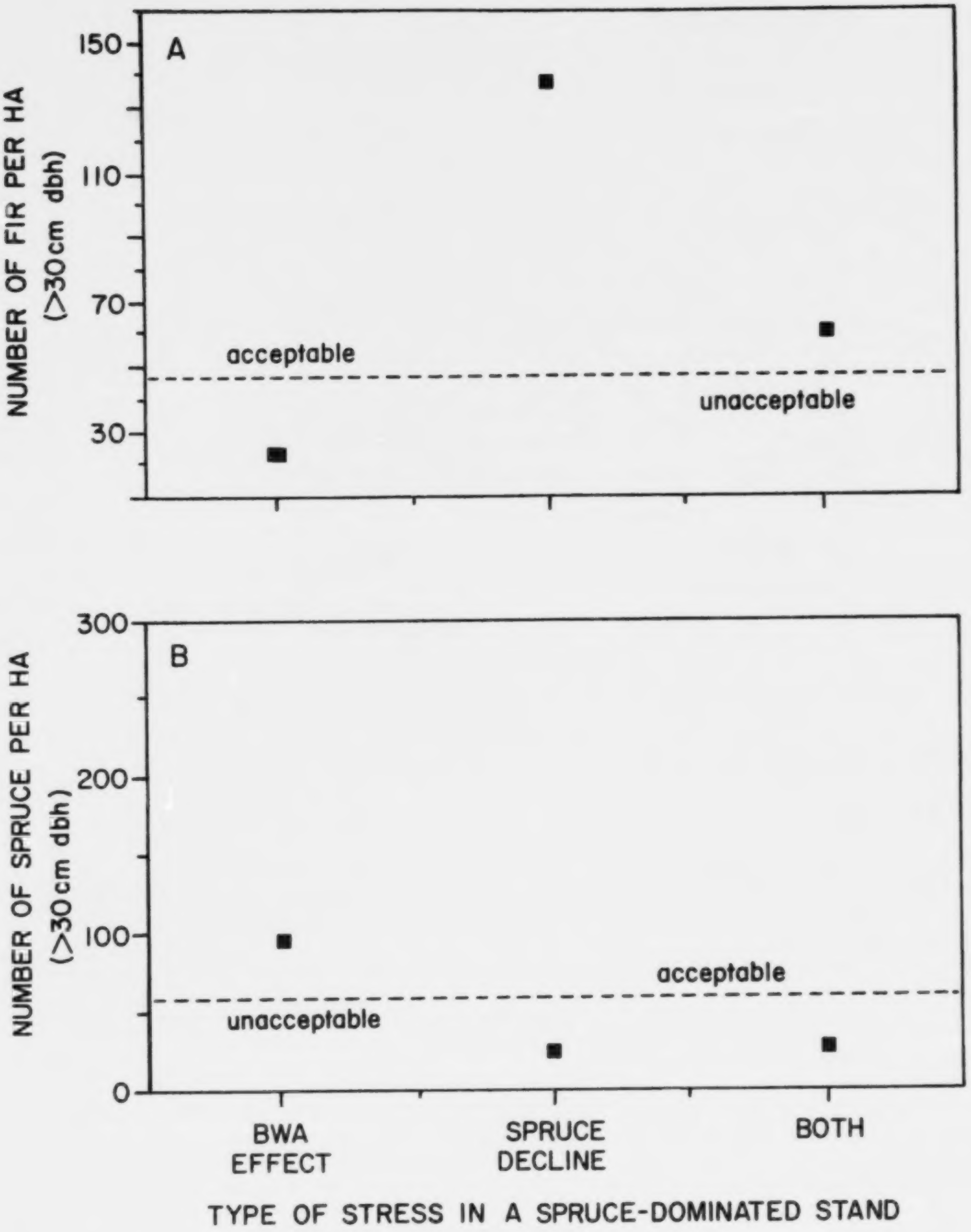

Figure 4.--An example of standards for acceptable and unacceptable ecosystem performance and simulated performance of old-growth spruce dominated stands under three stress hypotheses: (1) balsam woolly adelgid (BWA) causes 90% of fir trees > 30 cm dbh to die within two years; (2) realized annual dbh growth of red spruce is 50% of normal; and (3) a combination of effects (1) and (2); (a) number of fir > 30 cm dbh per ha; (b) number of spruce > 30 cm dbh per ha.

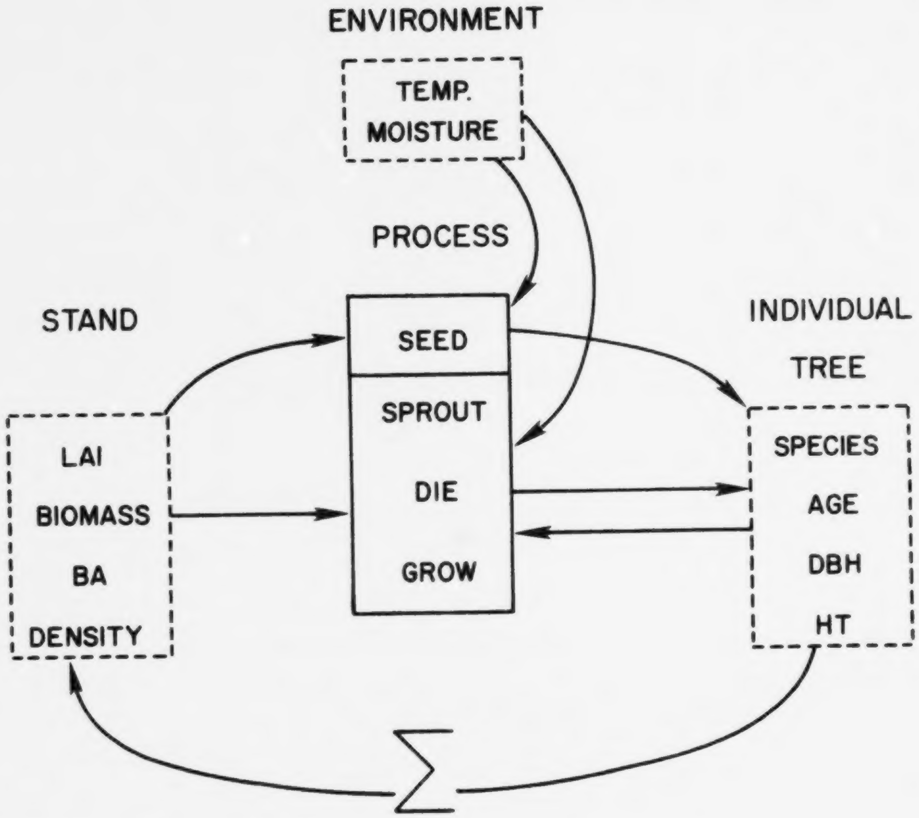

Figure 5.--Structure of FORET model.

is its reliance on general silvical characteristics, rather than on specific measurements, to provide input parameters. Yet, for shrub species such as mountain ash and mountain maple, which could become important in a stressed system, parameters for shade tolerance, size limits, etc. are largely guesswork.

Abiotic Environment

The abiotic environment in the model is described by monthly means and standard errors of temperature and precipitation, latitude, and field water capacity of the soil. For fir dominated areas, these data were estimated from weather records collected on Mt. Mitchell and from soil information collected by S.B. Feldman (VPI, personal communication). For spruce-dominated areas, the input data were estimated from TVA weather records (Chris Eagar, NPS, personal communiation) and from Stephens (1969). Comparison of weather records from the three study sites showed that anomalous variations in temperature and precipitation patterns from different elevations at the different sites could be attributed to differences in frequency of data collection (e.g., daily or monthly maximum and minimum temperatures) and methods of calculating means. Consistency in summarizing weather data being collected now by Mountain Cloud Chemistry installations is essential to their use as model input. A final descriptor of the abiotic environment is soil carrying capacity, the total biomass that can be supported on a particular site. This value reflects soil nutrient availability and limitations other than light or water. We used the few observations on biomass of southern Appalachian spruce-fir ecosystems to set this level, with a higher value being assigned to the lower elevation, spruce dominated stands.

Dbh Growth/Temperature

Functions describing diameter growth response to temperature required modification. The original parabolic representation of species temperature tolerances (Shugart and West 1977) did not match the observation that the largest, fastest growing individuals occur at the lower altitudinal and latitudinal limits of the species ranges. Switching to a trapezoidal relationship between potential diameter growth rate and annual growing degree days (Fig. 6), as suggested by Landsberg (1986), improved model behavior.

Shade Tolerance

The original FORET model (Shugart and West 1977) used only two tolerance classes to represent the reduction in potential diameter growth rates due to shading by taller trees. Following

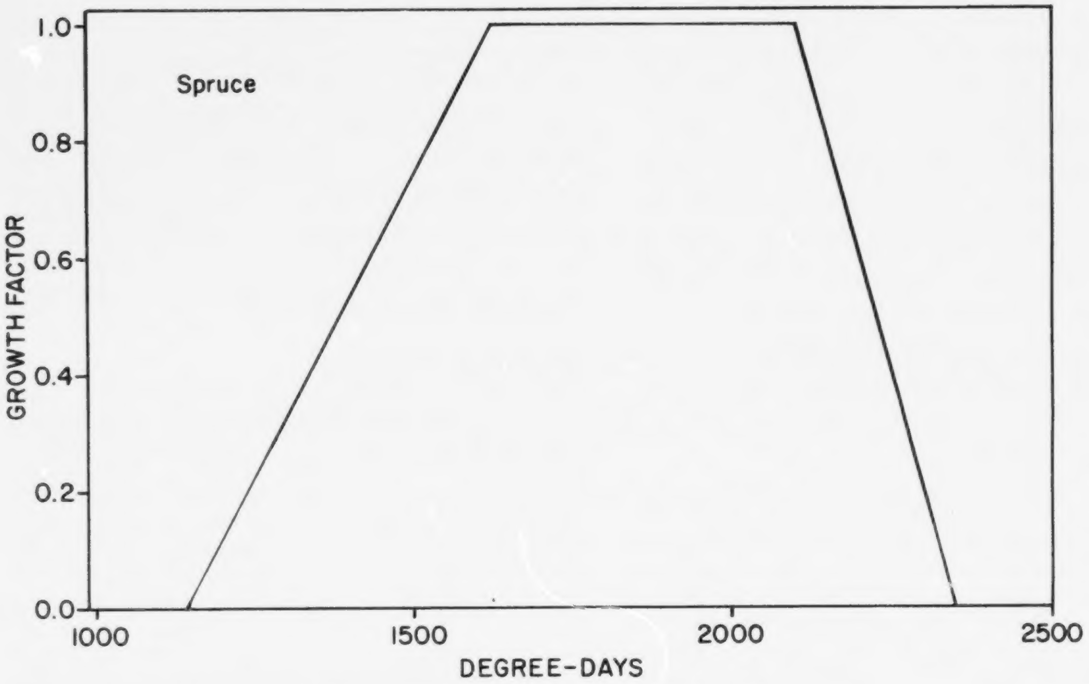

Figure 6.--Potential dbh growth of red spruce as a function of annual growing degree days.

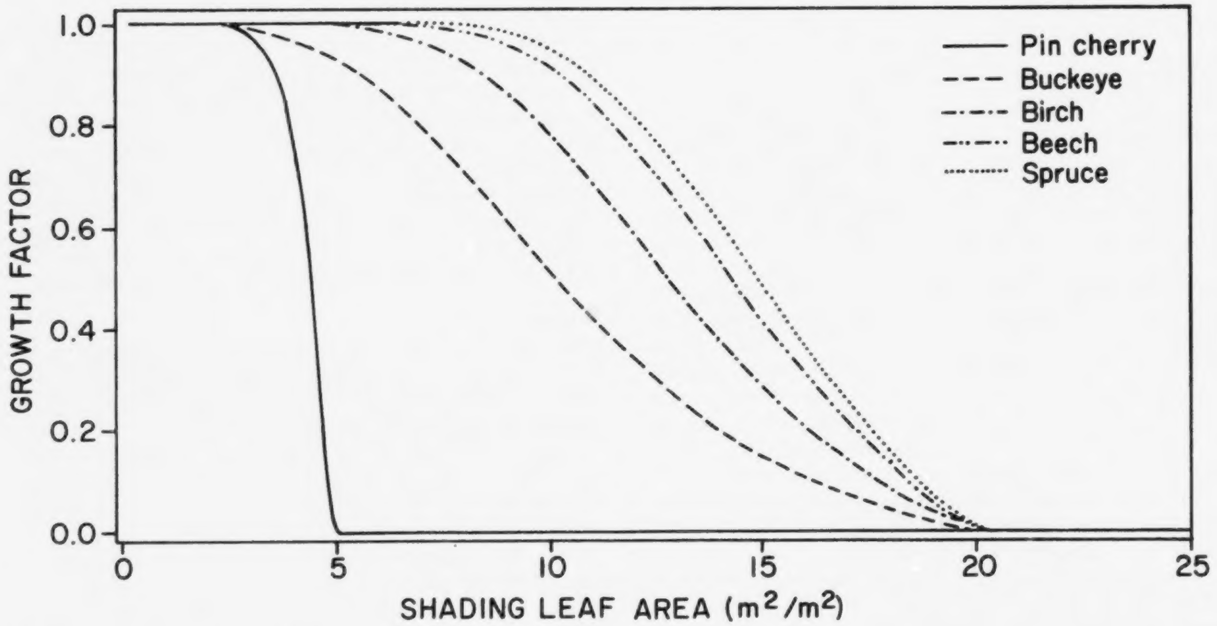

Figure 7.--Reduction in potential dbh growth due to shading for different tolerance classes.

the lead of Dale and Hemstrom (1984) in adapting FORET to northwestern coniferous forests, we used five tolerance classes to better span the range of species responses to shading and release (Fig. 7). Both fir and, particularly, spruce tolerate heavy shade, but respond with increased growth to gaps in the canopy. Suppressed trees suffer increased mortality. We used three categories of tolerance to suppression in our version of the model: (1) the most tolerant (e.g., fir, spruce) experienced increased mortality only when annual dbh growth dropped below 0.045 cm; (2) other tree species (e.g., yellow birch) had increased mortality when annual dbh growth dropped below 0.1 cm; and (3) the least tolerant (shrubs, such pin cherry, striped maple) had increased mortality at less than 0.15 cm/year dbh growth. In addition to suppression mortality, older trees experienced a greater probability of death, with only 1% surviving to the maximum age for the species.

Biomass/Dbh

The model projects diameter growth, and then calculates other tree parameters (e.g., height, leaf areas, biomass) as functions of diameter. For many tree species, and particularly for high elevation, these functions are poorly known. Whenever possible, we have replaced general functions with functions for particular species (Fig. 8), preferably derived from southeastern data. One limitation to the functions in Figure 8 is that some are based on data from relatively small trees, but the model must project parameters for larger trees, especially large spruce. Field studies being conductd by other cooperators will help revise these functions for southern Appalachian spruce-fir. To help direct laborious field measurements sectioning and weighing tree parts, we plan to analyze the sensitivity of the model to variations in biomass and leaf area functions.

Model Validation

Model validation ensures that the model is an adequate tool for projecting system performance. We used our knowledge of "normal" system behavior to develop numerical criteria for validation. For indicators which are highly variable naturally, such as stem density, the criteria are less stringent than for others, such as biomass or leaf area. In making the validation runs, we found that forest conditions used to initialize the model (e.g., bare ground, postlogging status, current status) affected system behavior for 200 to 400 years (Fig. 9). In addition, remnants of synchronous regeneration persist as mild cycles with periods approximating the life spans of the major species (about 150 years for fir and about 400 years for spruce). To properly simulate the dynamics of both old-growth and second-growth stands, we matched the initial conditions to the likely disturbance histories of these forest types, compiled by Pyle and Schafale (1985). We hypothesized postlogging conditions for the second-growth stands (e.g., no spruce greater than 20 cm, abundant advance regeneration of fir) and used these to initialize 100 year runs. The output measures (e.g., density, biomass) were averaged over the last 30 years for comparison with the validation standards (Fig. 3). For old-growth stands, we used current conditions from old-growth stands to initialize 300 year runs and averaged output measures over the last 50 years for comparison with the validation standards. Most, but not all, of the simulated values fall within the validation criteria we proposed. Because of the severely limited data for model development and validation, we have not reserved part of the data for validation alone, making our comparisons weaker tests of model performance than they would be if judged against a completely independent data set. Field observations from subsequent years could perhaps be reserved for this purpose. In addition to the quantitative tests, we examined the qualitative behavior of the model for appropriate response to tests such as drought conditions, elimination of dominant species, and changes in elevation (via temperature).

Hypothesized Effects

One of the main purposes of the modeling is to provide a framework for projecting stand level impacts of air pollution or other stresses acting on individual trees. We have just begun this process. Figure 4 shows several examples where growth and mortality rates have been changed, the model run forward from current conditions, and 30 year and 200 year averages of the output measures computed for comparison with system performance standards indicating acceptable and unacceptable behavior. Note that the altered growth and mortality rates reflect hypothesized effects of any stress or combination of stresses, not necessarily air pollution. As better dose-response data become available from field and laboratory experiments, we will use them to select the types and magnitudes of stress effects to analyze using the model. These effects can be imposed at any stage of the model, from changing potential growth rates of individual trees through changing realized annual growth or mortality, reflecting the influence of the biotic and abiotic environments on individual tree processes. We can also use the model to test hypotheses relating to reductions in effective leaf area or biomass over the whole stand, which will in turn impact the growth and mortality processes of individual trees. By testing a wide range of possible effects of air pollutants on tree growth and mortality, we will deduce those that are likely to produce unacceptable system behavior. This outline of system response will help researchers and managers focus field and laboratory research, revise standards for acceptable ecosystem performance, and direct the attention of regulatory decision makers to critical elements.

Future Work

Plans for future development and application for the model include additional tests of hypothesized effects of air pollutants and other stresses. We also intend to continue to improve the model's representation of the spruce-fir system by (1) examining the impact of revisions in dbh-biomass, dbh-leaf area, and mortality functions on system behavior; (2) introducing more physiological detail in the growth and mortality functions, mainly through whole tree modeling of carbon dynamics; (3) simplifying the stochastic features of the model to eliminate those that do not contribute significantly to system behavior; and perhaps, (4) making a more comprehensive sensitivity analysis of the adapted model using supercomputer facilities. Our interactions with researchers doing field and laboratory studies will continue, although it is unrealistic to expect the full benefit of this interaction to be realized within a short time frame.

Acknowledgments

We thank Virginia Dale and Darrell West of Oak Ridge National Laboratory for their advice on adapting FORET. We thank Chris Eager, Niki Nicholas, Shep Zedaker, Bob Bruck, Lucien Zelazny, S. Feldman, and Noel Cost for sharing field and laboratory data.

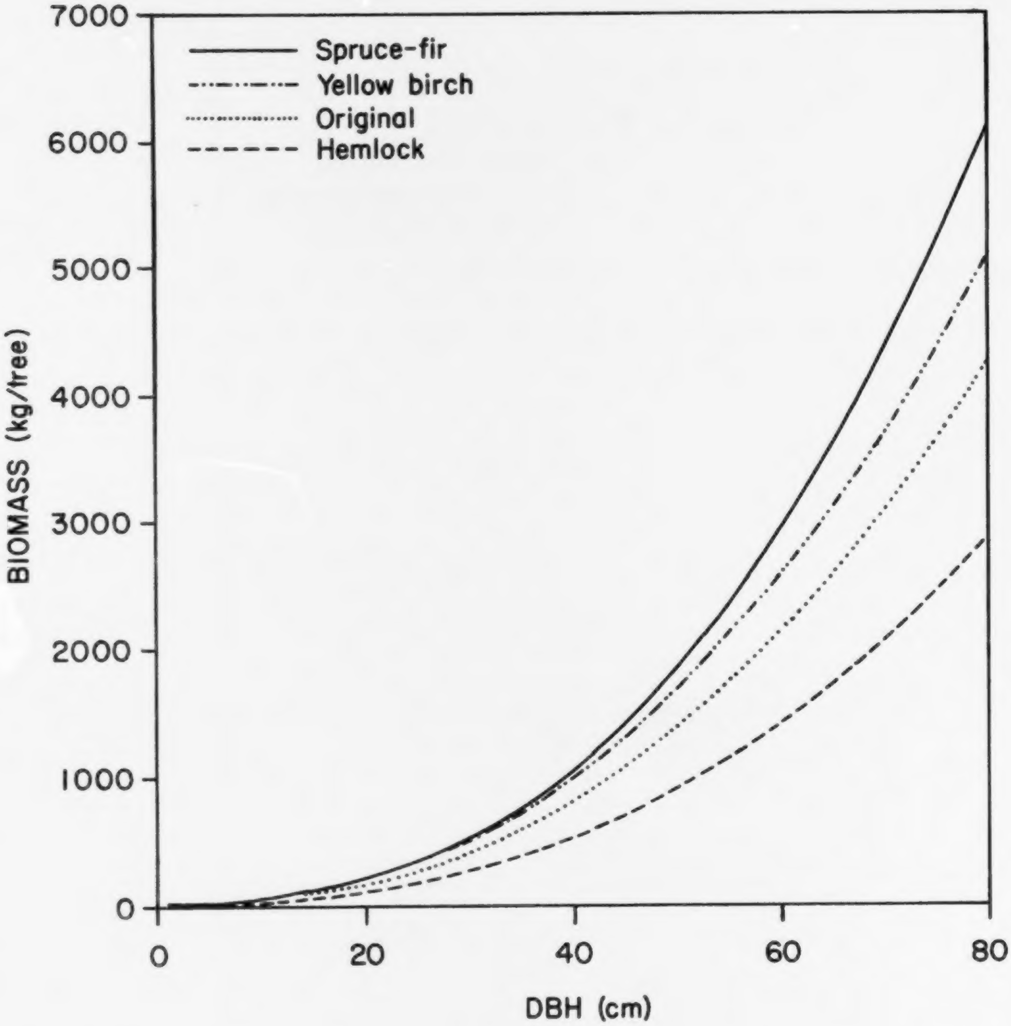

Figure 8.--Biomass as a function of dbh for southern Appalachian spruce-fir species. General function from original FORET code (Shugart and West 1977); spruce and fir functions from Craver (1985); yellow birch and hemlock from Tritton and Hornbeck (1982).

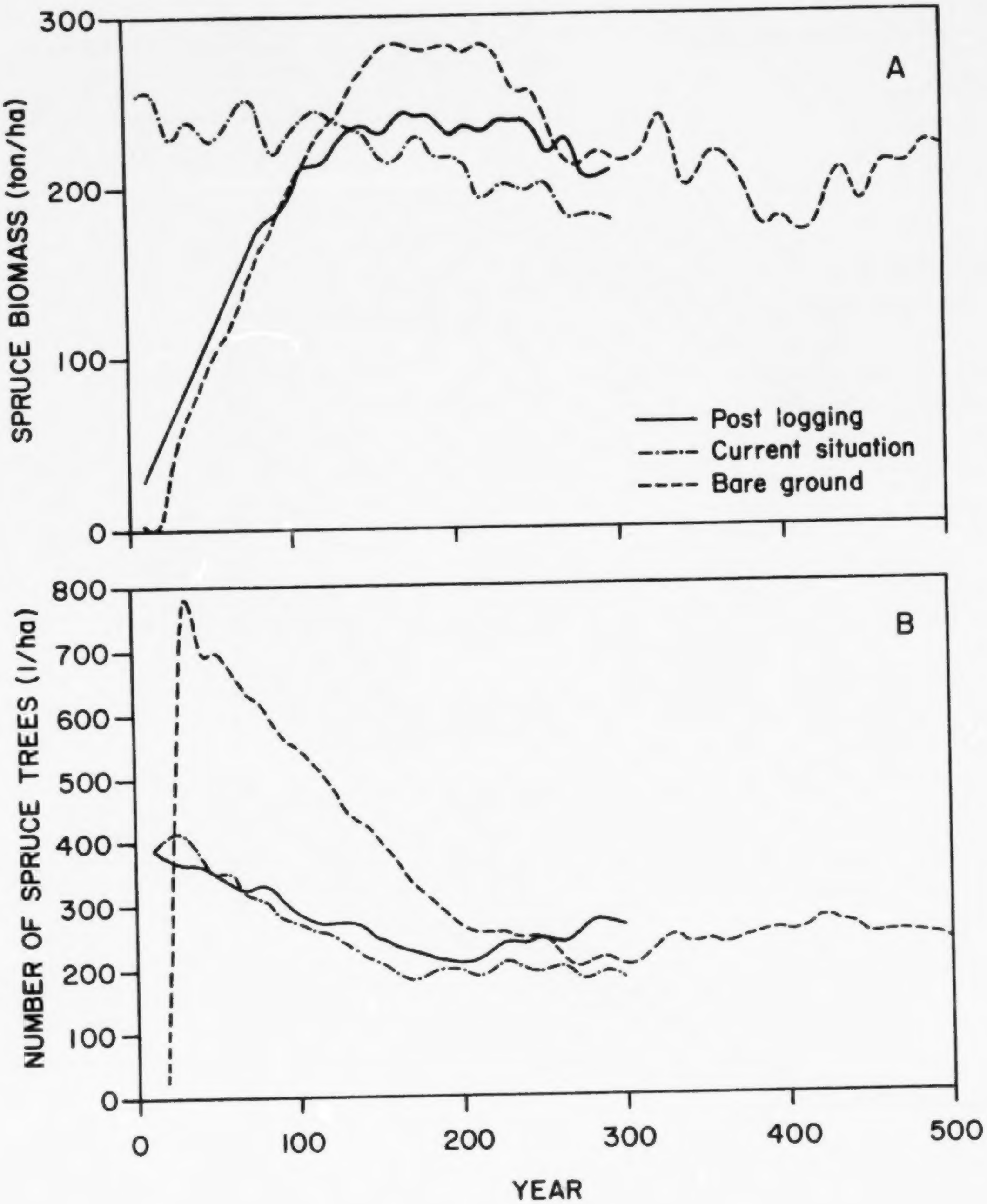

Figure 9.--Impact of initial conditions on spruce-fir dynamics; average of 25 replicates of old-growth spruce dominated stands; (a) biomass for spruce > 2.5 cm dbh; (b) number of spruce > 10 cm dbh per ha.

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Relationships Between Red Spruce Decline and Forest Characteristics at Whiteface Mountain, New York

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Abstract

Over the past 20 years, there has been a deterioration of red spruce in the montane forests of the Adirondack, Green and White Mountains. Surveys of vegetation characteristics at Whiteface Mountain in the Adirondacks (NY) during the 1960's and 1980's showed that red spruce decline has occurred at all elevations, and in stands which have a wide range of species composition and disturbance histories. The deterioration of red spruce has been most pronounced above 1000 m, and on the northwest aspect and individuals over 30-cm dbh appear to have been affected to the greatest extent.

Introduction

The well-documented mortality and growth reduction of red spruce (*Picea rubens* Sarg.) trees in the montane forest of the northeastern United States has led to a focused research effort directed by the USDA Forest Service (U.S. Environmental Protection Agency and U.S. Forest Service, 1986). Earlier work on red spruce decline (Johnson and Siccama 1983, Johnson and McLaughlin 1986) suggested that several factors may contribute to the unusually severe mortality and recommended that those factors should be studied to determine their degree of involvement. This paper presents a regional overview of mortality in the high-elevation forests in the Northeast and then using Whiteface Mountain, New York as a case study, analyzes the degree to which elevation, aspect, and tree age are associated with the occurrence and degree of spruce mortality.

Regional and Temporal Overview

The patterns of vegetation on the mountains of the Northeast are complex mosaics which result from environmental gradients (e.g. climate and soil characteristics), natural disturbances (e.g. windthrows, insects, disease and land slides), and anthropogenic influences (e.g. logging, trails, campsites). Smaller-scale disturbances (< 1 to 20 ha) also have important effects on species composition and the age structure of the forest (see Foster and Reiners 1983).

Well-defined relationships exist between stand composition and environmental conditions on the mountains of the Northeast. These have been studied by several investigators (Adams et al. 1920, McIntosh and Hurley 1964, Harries 1966, Holway et al. 1969, Scott and Holway 1969, Siccama 1974, Foster and Reiners 1983). Sugar maple (*Acer saccharum* Marsh) is the most important canopy species below 700 m, and balsam fir (*Abies balsamea* (L.) Mill.) is the most important above 900 m. Red spruce is a relatively small component of the hardwood forest (below 700 m), and is very rare above about 1200 m. White birch (*Betula papyrifera* Marsh.) is dominant in disturbed areas and occurs throughout the range of red spruce and balsam fir. Elevational gradients for Whiteface Mt., are shown on figure 1.

The condition of spruce in high-elevation forests changed substantially between the mid 1960's and the early 1980's at Whiteface Mountain and elsewhere in the Northeast (Siccama et al. 1982, Scott et al. 1984). At Whiteface Mt., stand basal area decreased by 20-30%, accounted for largely by reductions in live spruce basal area of over 50% (Scott et al., 1984). Surveys of fifty-six 100-m transects on Whiteface Mountain, Mount Mansfield (VT) and Mount Washington (NH) in 1982 and 1987 show the recent progress of the spruce decline (figure 2). Above 900 m, the majority of trees which showed severe crown dieback in 1982 (crown class 3 trees with >50% foliage loss from the the upper third of the live crown) died, while the percentage of spruce in crown classes 1 and 2 (class 1: <10% of foliage loss from upper crown; class 2: 10-50% foliage loss) was unchanged. Apparently, trees which were vigorous in 1982 did not begin to decline in the subsequent five years.

Below 900 m the pattern in the Northeast was different. Severely declining trees (crown class 3) were rare at lower elevations in 1982 and 1987. There was a decrease in crown class 1 trees with a corresponding increase in dead spruce (figure 2). This five-year change in the proportion of healthy to dead spruce trees suggests rapid death of visibly healthy trees. In the Crawford Notch area near Mount Washington considerable spruce mortality in the low-elevation forests has been attributed to spruce beetle (*Dendroctonus rufipennis*), a primary pathogen that causes rapid death (Spruce-Fir Research Cooperative's pest and pathogen training session, spring 1987), thus indicating a possible explanation for the rapid mortality at low elevation. Of the three main sites, the greatest mortality between 1982 and 1987 occurred at Whiteface Mt. (figure 3).

Relationships Between Mortality and Elevation, Age, and Aspect at Whiteface Mountain

Methods

An extensive vegetation survey was begun on Whiteface Mountain in June 1986 and completed in June 1987. An unbiased sampling of the forest was obtained by randomly superimposing a twenty-one transect rectangular grid on the Whiteface Mountain massif (total area 3326 ha). Circular sampling plots (10 m diameter) were located 120 m apart on the grid lines which ran approximately perpendicular to the topographic contours. All trees greater than or equal to 50-mm dbh were measured and recorded as live or

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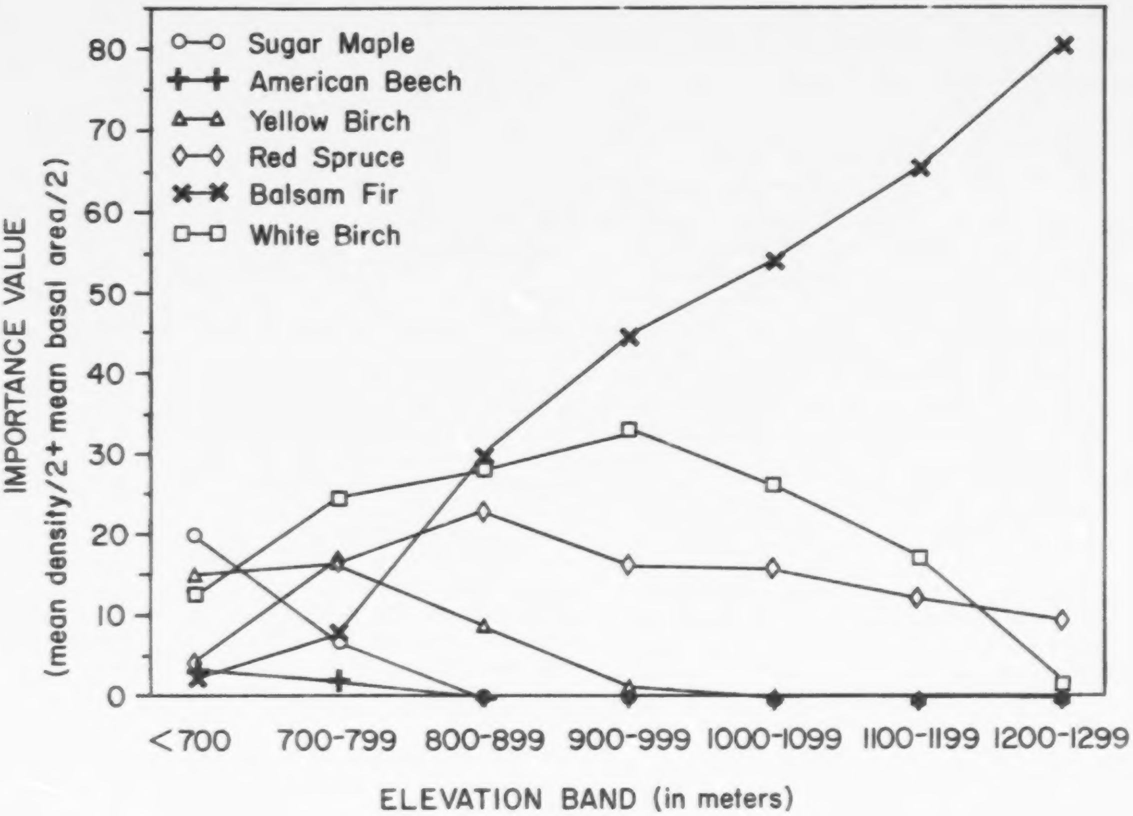

Figure 1.--Relative importance values for major canopy species at Whiteface Mt. in 1986-87.

dead by species. A total of 331 plots were established and over 7,000 trees were measured. In addition, slope, aspect, elevation, landform, slope position, and microrelief were determined in these plots.

Results

Elevation Patterns

Figure 4 graphs the percentage of dead spruce as a function of elevation. There is no statistical difference in the percentage of dead spruce in the three lower elevation bands where approximately 25% of the standing spruce trees are dead; there is also no statistical difference in the percentage of dead spruce in the three higher elevation bands where approximately 55% of the standing spruce trees are dead. This figure clearly shows that there is an abrupt increase in the percentage of dead spruce at roughly 1000 m.

Figure 5 plots percent of live spruce by size class. Assuming that the current percentage of standing dead stems reflects mortality rather than the tendency for larger dead spruce to remain standing longer than small dead spruce, there has been greater mortality in the larger size classes both below 1000 m and above 1000 m. Additionally, there is a higher percentage of dead spruce in every size class above 1000 m compared to below 1000 m.

Aspect Patterns

Figure 6 shows dead spruce on the northwest exposure of Whiteface Mountain as a function of elevation. While the general trend of more dead spruce in the higher elevation bands is apparent (see figure 4), the difference between the higher bands and lower bands is more pronounced. Figure 7 graphs the percent of live spruce by aspect and size class for the trees above 1000 m. On the upper slopes, there was a higher percentage of dead trees on the northwest face in all but one of the size classes.

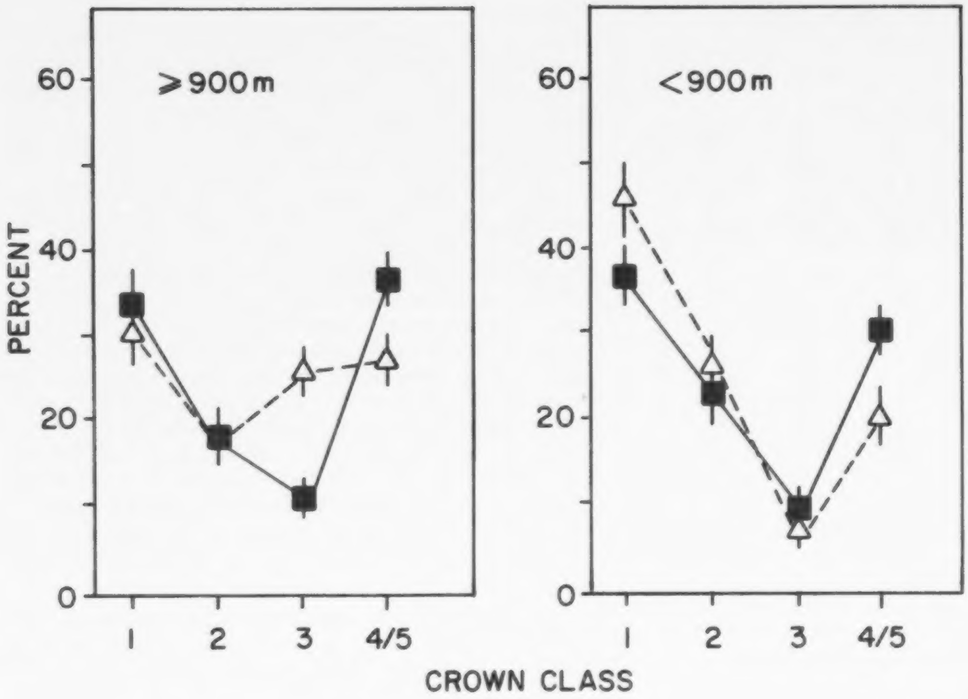

Figure 2.--Changes in red spruce crown class between 1982 and 1987 for elevations at or above 900 m and below 900 m at Mt. Washington, NH, Mt. Mansfield, VT, and Whiteface Mt., NY. Crown class 1 trees have 0-10% loss of foliage from the upper portion of the live crown, 2 = 10-50% foliage loss, 3 = >50% foliage loss from live crown, 4 = standing dead or dead, 5 = broken above dbh.

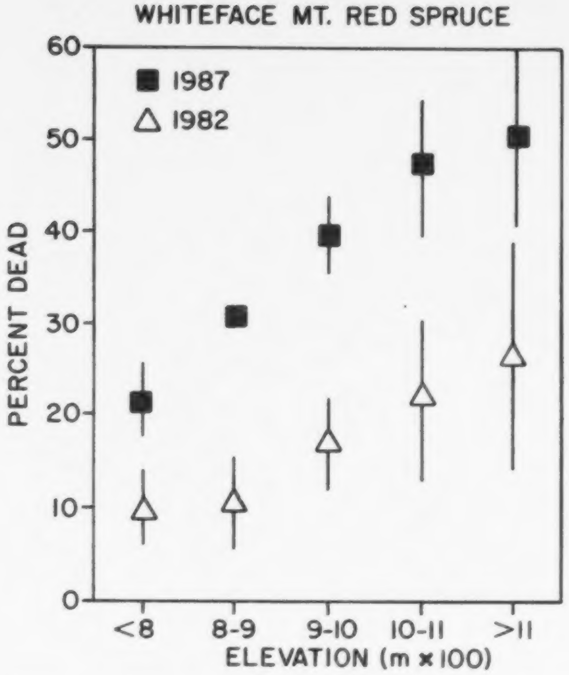

Figure 3.--Changes in the percentage of the spruce which were dead at Whiteface Mt. between 1982 and 1987 as a function of elevation. Standard errors are calculated on the basis of the number of transects (usually 3 or 4) which occurred in each elevational zone.

Figure 8 compares the distribution of dead spruce to the distribution of dead fir and illustrates the differences between wind-exposed sides (northwest and southeast) and the more sheltered sides (northeast and southwest) of the mountain. Mortality is more pronounced for both fir and spruce on the wind-exposed faces especially at higher elevations, but the degree and distribution of dead trees is different for the two species.

Age Distribution

Figures 9 and 10 use diameter distributions as a measure of age distribution. In the forests below 1000 m, red spruce has the expected age distribution of a stable population with more smaller (younger) trees with a gradual decrease in number with increasing size (age) until the number of stems plateau in the largest (oldest) cohorts. Associated species have a similar distribution in both below 1000 m and above 1000 m, however in the forests above 1000 m, the diameter distribution curve for spruce is flattened because there are relatively fewer small spruce stems as compared to large stems. Although figure 10 suggests a declining spruce population above 1000 m, the survivorship characteristics of spruce and fir are not well enough established to confidently predict their long-term future. Data on reproductive size classes are needed in this regard.

Discussion

It is clear from figure 4 that there are more dead spruce stems on the higher slopes of Whiteface Mountain. This difference is not just an artifact of a species-specific distribution strategy along an environmental gradient. Red spruce is not at the edge of its elevation range at 1000 m on Whiteface Mountain. As measured by importance value, spruce is a significant component of the forests above 1000 m (figure 1). The findings that there are proportionally more big spruce at the higher elevation and that there is generally a higher percentage of mortality in larger trees partially explain the greater percentage of dead stems in the higher elevation bands. In other words, assuming that the increase in dead stems in larger size classes truly represents more mortality of older trees (and not the tendency of large dead trees to remain standing longer than small dead trees), the distribution of size classes prior to the recent mortality of red spruce helps account for the greater percentage of dead spruce trees above 1000 m. Thus processes which have affected the age structure of the forest (e.g. logging and fire) have had some impact on the spatial distribution of dead stems. However, the greater percentage of dead stems in all size classes of spruce at the higher elevations indicates a real association between elevation and the severity of spruce decline.

At Whiteface Mountain, mortality of red spruce is greatest on the upper slopes of the northwest face compared to other exposures at the same elevation, and this relationship is suggested across almost all size classes. The northwest aspect has the most pronounced development of fir waves and hence, a greater percentage of dead balsam fir. According to Sprugel (1976), the fir waves are caused by the northwest winter winds that cause mechanical damage to the branches and needles of ranks of exposed, mature balsam fir above 1100 m. The waves tend to "spill over" to the southeast aspect, so we grouped those sides together for comparison. As is the case for fir, the increase in winter stress above 1100 m may account for the different degree of spruce mortality observed between aspects.

Impact of Red Spruce Decline on the Forest

Age and poor site conditions are factors thought to control, in part, the severity of other declines (e.g. Houston 1981, Manion 1981, Weiss and Rizzo 1987). At Whiteface, and elsewhere, the upper slopes have thinner, more acidic soils, considerably shorter growing seasons, greater exposure to airborne chemicals, greater wind stress, and are, in general, poorer sites than the lower elevations. Thus, the associations between elevation and dead spruce and aspect and dead spruce suggest that poor site conditions are a factor related to the severity of decline. Likewise, tree age appears to be a factor related to the spatial patterns of decline severity.

Our observations suggest that balsam fir and white birch reproduction has been very rigorous in the gaps left by dying spruce, and over the lifetime of the birch and fir (100-150 years), the species composition of the canopy layer and the processes which regulate energy and nutrient flow will shift accordingly. The current distribution of live-tree diameters for spruce and the

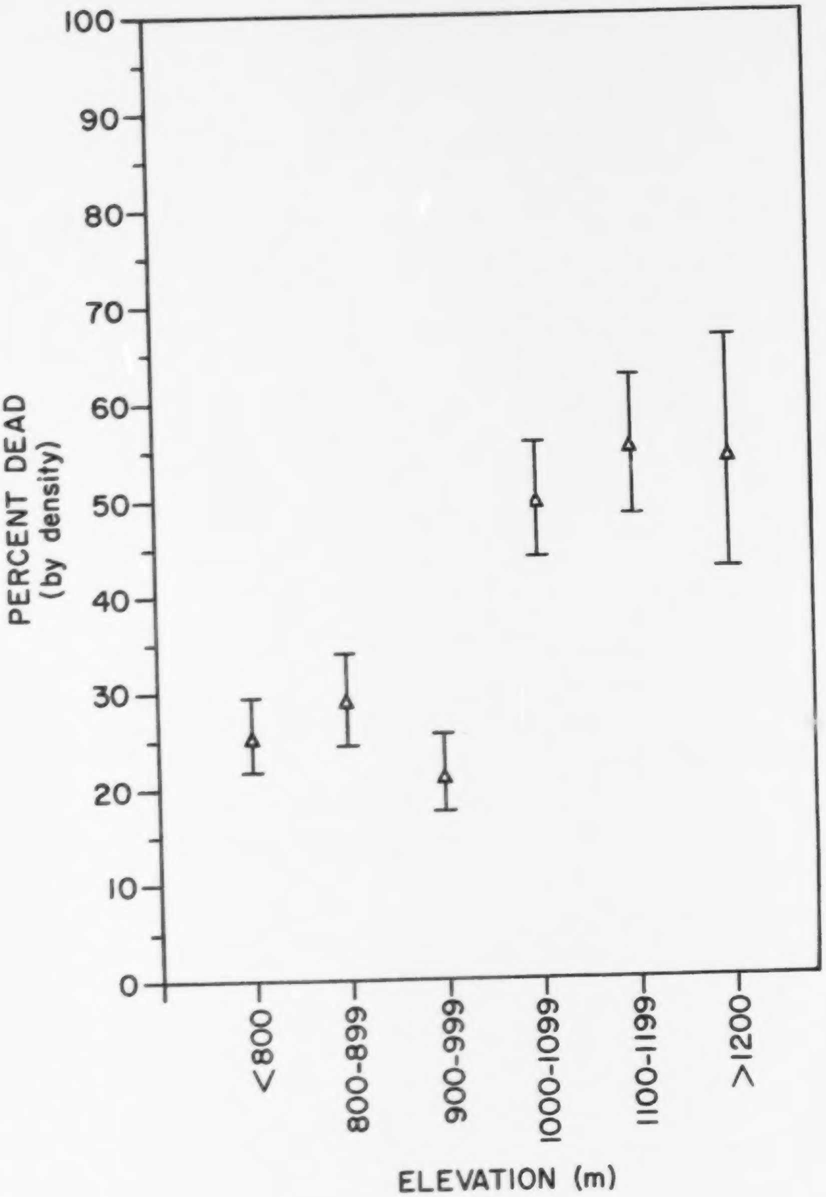

Figure 4.--Percentage of the red spruce population which is dead as a function of elevation on Whiteface Mt., NY.

other associated species above and below 1000 m at Whiteface Mt. suggest a declining spruce population above 1000 m and a stable one below 1000 m. A better picture of the future of red spruce will emerge when data on reproductive size classes have been analyzed. Since red spruce are so long-lived (over 300 years) compared to fir or birch, and extremely shade-tolerant, the survivors of the current decline may be sufficient to allow the population of understory spruce to increase, and ultimately replace fir and birch in the canopy as they die off a century from now. The shade tolerance and longevity of spruce should allow

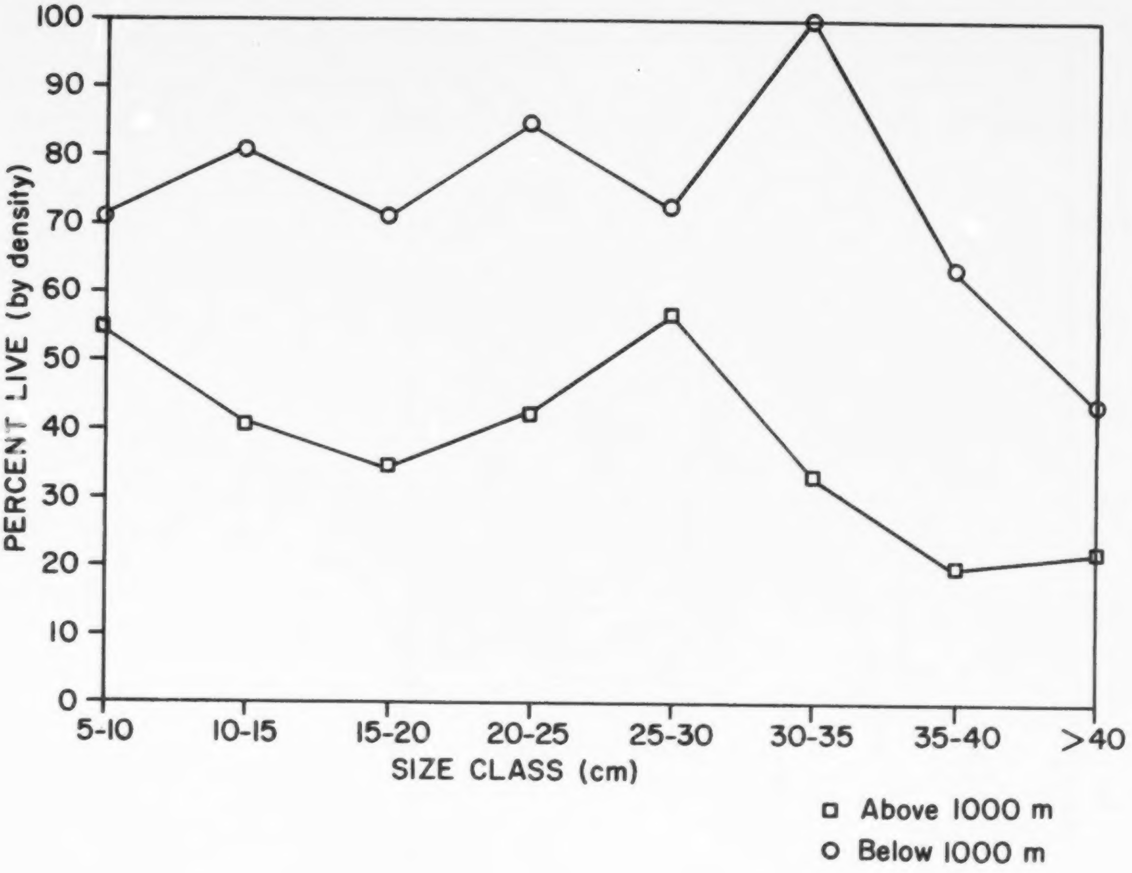

Figure 5.--Percentage of the red spruce alive in each size class at Whiteface Mt., NY.

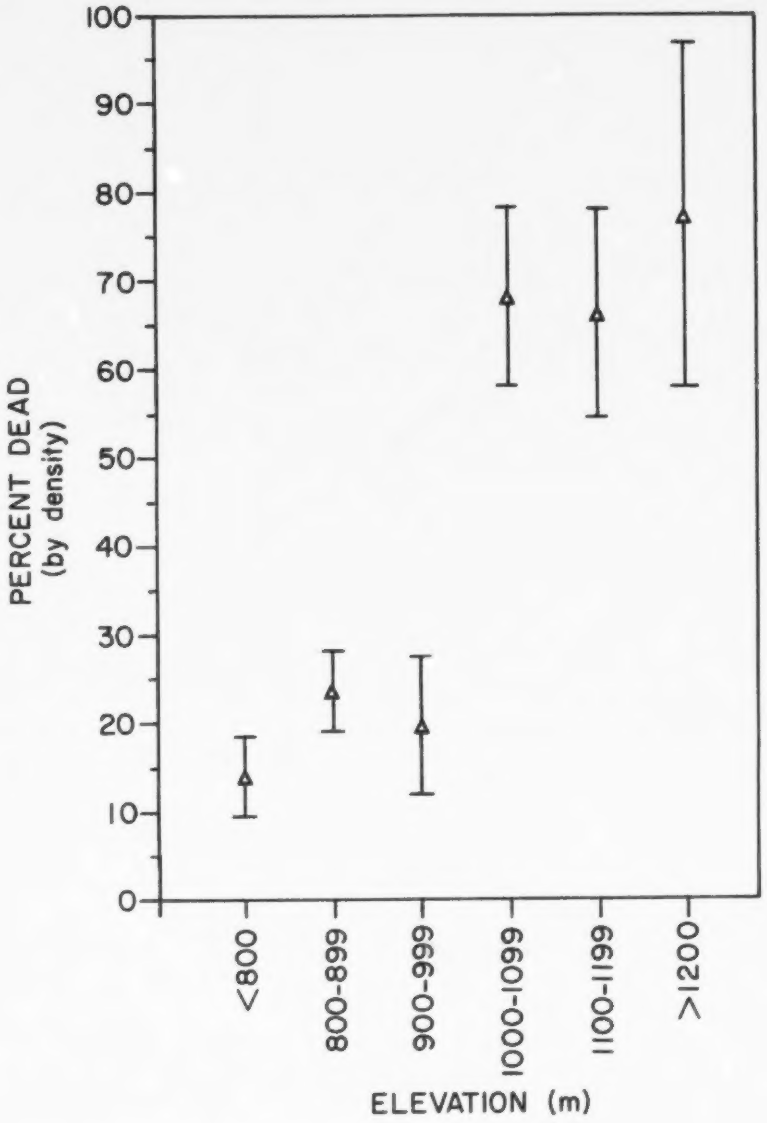

Figure 6.--Percentage of the red spruce on the northwest aspect of Whiteface Mt, NY which are dead as a function of elevation.

that species to undergo serious declines periodically, then return in future years as an important species in the canopy. Thus, if the spruce decline has only natural causes, the observed decline may be only part of a normal cycle in an ecosystem which is stable when viewed over long periods of time.

Acknowledgments

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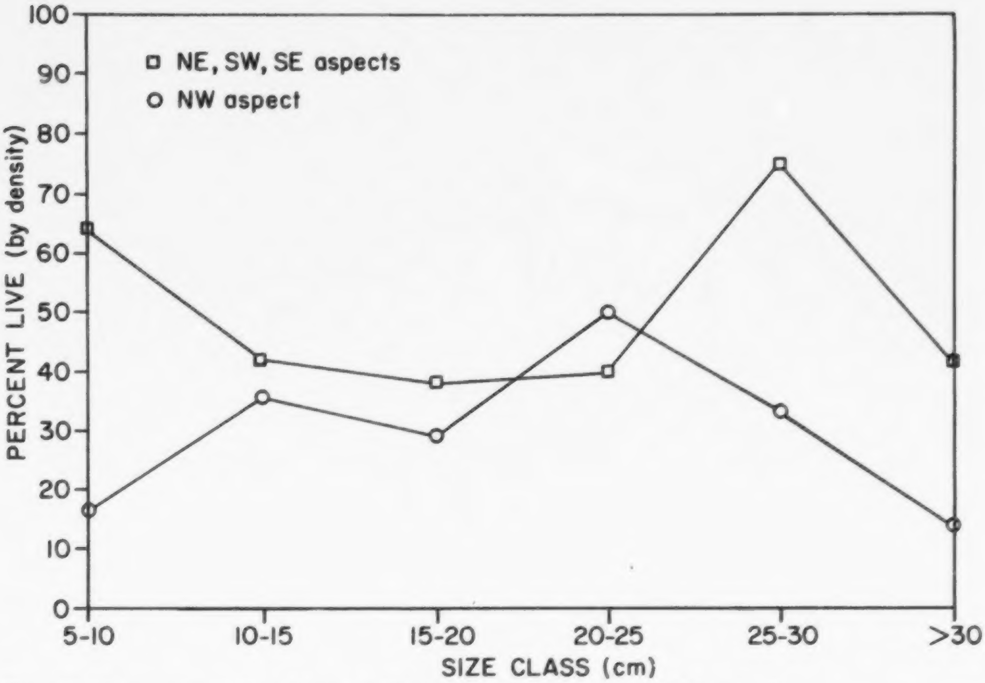

Figure 7.--Percentage of the red spruce alive in each size class above 1000 m on the northwest aspect compared to the other three aspects (NE, SE, SW) combined.

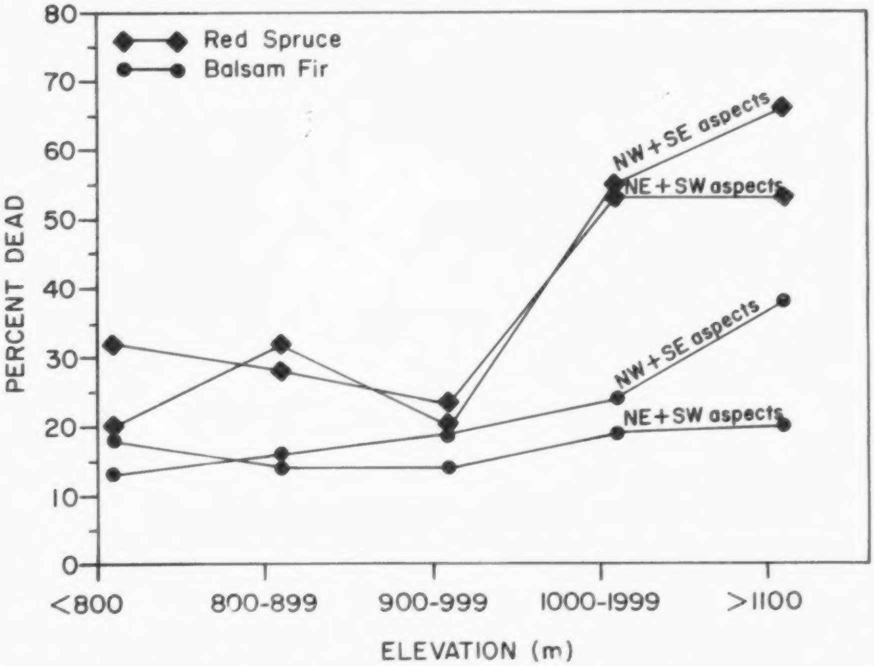

Figure 8.--Distribution of dead red spruce and balsam fir by aspect and elevation.

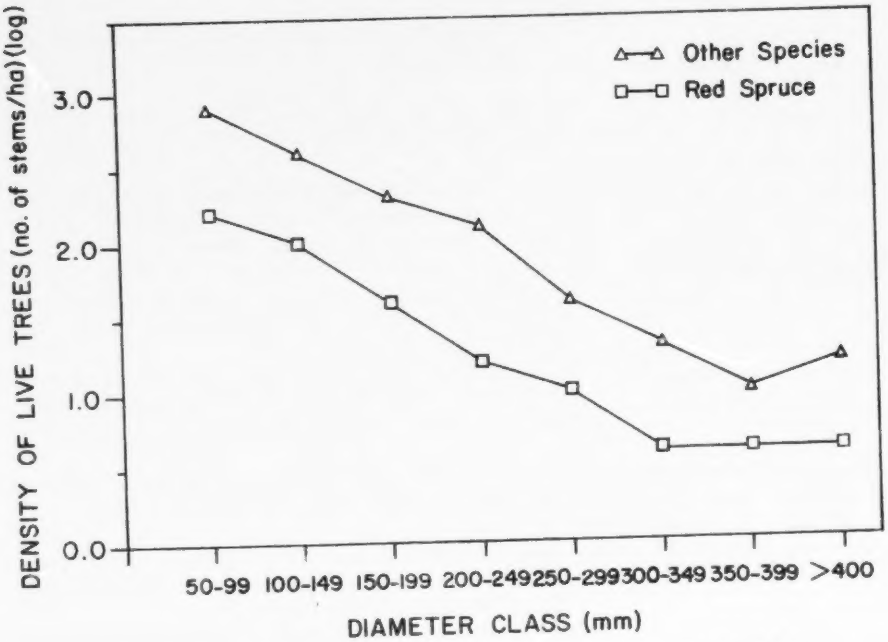

Figure 9.--Distribution of red spruce and associated species by size class for plots below 1000 m.

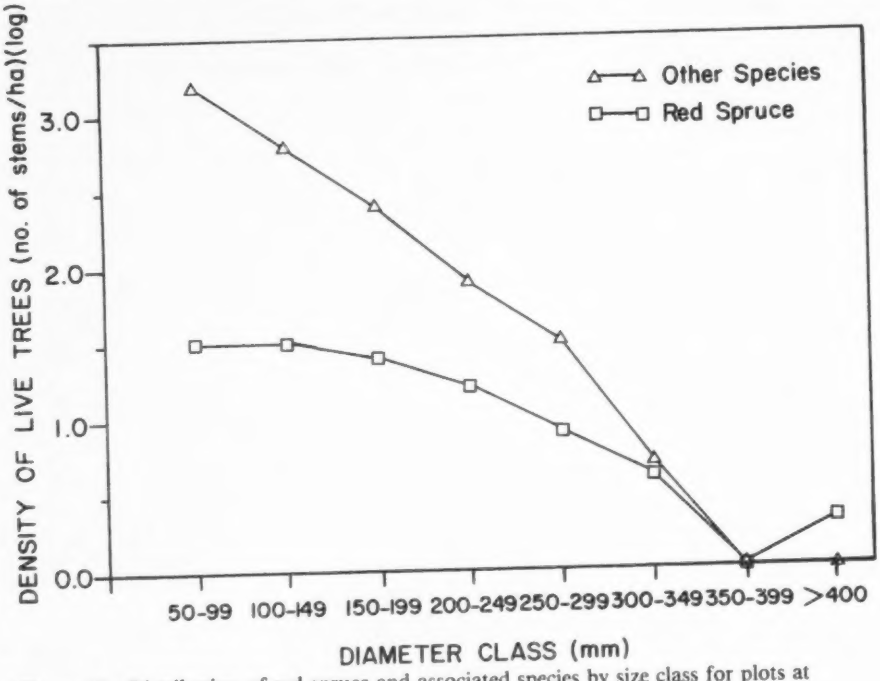

Figure 10.--Distribution of red spruce and associated species by size class for plots at or above 1000 m.

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Condition of the Spruce-Fir Forest at Mount Moosilauke, New Hampshire.

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Abstract

*The condition of red spruce (**Picea rubens** Sarg.) is worse than that of balsam fir (**Abies balsamea** (L.) Mill.) in the spruce-fir forest at Mt. Moosilauke, N.H., in terms of percent standing dead and crown condition, in permanent plots stratified by elevation (840, 990 and 1140m), aspect (east and west) and soil type (cryofolists and spodosols), and in terms of recent growth decline evident in increment cores. Elevational and aspect trends in spruce and fir condition are not strong or consistent, but there is some evidence for increased proportions of dead spruce and fir on cryofolists compared to spodosols at middle elevations.*

Introduction

In this paper we present preliminary, summary analyses of field data collected during the 1986 and 1987 field seasons on percent standing dead, crown condition and growth trends for red spruce (*Picea rubens* Sarg.) and balsam fir (*Abie balsamea* (L.) Mill.). Our preliminary results are presented here as an in-progress report that may be of interest to other groups working on forest decline in spruce-fir ecosystems. This is part of a larger effort to characterize the temporal and spatial pattern of growth and mortality in the spruce-fir forest at Mt. Moosilauke, and to examine the relations betwen those trends and natural and anthropogenic influences. Mt. Moosilauke is one of the intensive research sites within the U.S. Forest Service Eastern Spruce-Fir Research Cooperative (United States Department of Agriculture et al. 1986). Our survey data provide a baseline for future monitoring, and a reference for other research focusing on specific mechanisms that may be responsible for forest decline. Atmospheric inputs will be obtained from a new meteorological station at the research site, and from substations set up to examine spatial variation in deposition within the study area.

Study Site

Mt. Moosilauke, N.H. (1465m), in the southwest portion of the White Mountains, has the full elevational range of spruce-fir forests in the northeast (760m to 1220m), and a north-south major ridge line separating west facing slopes, exposed to the prevailing winds, from more protected east and south-east facing slopes. Geology, vegetation and climate of high elevation forests in the White Mountains are summarized in Reiners and Lang (1979). The vegetation and biogeochemistry of the fir zone (1220m to 1450m) has been extensively studied by Reiners and associates. The higher peaks in the Mt. Moosilauke massif, and most of the study area, are owned by Dartmouth College and used only for recreational , scientific and educational purposes. The Dartmouth owned land is surrounded by the White Mountain National Forest, which includes part of the study area. The soils of the spruce-fir zone on Mt. Moosilauke are described in Huntington and Ryan (1988). At lower elevations, the soils are dominated by spodosols. At middle elevations, cryofolists and spodosols are approximately equally represented, and at higher elevations, the cryofolists dominate. The spruce-fir zone has a varied history of disturbance by logging and a major hurricane in 1938 (C. Cogbill, unpublished data). Both types of disturbance are common features of spruce-fir forests in the White Mountains.

The recently established meteorological station, at 975m on a knoll approximately 4km southeast of the main peak, is operated under the Mountain Cloud Chemistry Program. Smaller stations, termed Portable Meteorological Units, or PMU's (Hornig et al. 1988), have been established near the main station for calibration, and at 6 locations in the study area so that vegetation and atmospheric data can be correlated.

Methods

Permanent Intensive Plots

West facing slopes may have different exposure to atmospheric pollutants from more protected east facing slopes. High elevations have more total precipitation, higher inputs of anthropogenic substances, a greater exposure to clouds, a more extreme climate and a shorter growing season than at low elevations. Also, soil types may differ in nutrient pools or susceptibility to leaching loss. Intensive plots were therefore tightly stratified by elevation, aspect, and soil type. Contours at 840m, 990m, and 1140m were surveyed on both east and west facing slopes, and soils probed and vegetation assessed at points every 20 paces (approximately 30m). At each point, soils were classified as cryofolist or spodosol, and the approximate forest composition assessed in terms of percentage of total basal area contributed by conifers (spruce and fir), and the percentage of total basal area contributed by spruce. Locations were rejected for permanent plots if they contained less than 40% basal area of conifers, less than 5% estimated basal area of spruce, or if slope was greater than 38°. At 840m (low elevation), plots were placed only where soils were classified as spodosols, at 990m (middle elvation), plots were placed on both spodosols and cryofolists, and at 1140m (high elevation), plots were placed only on cryofolists. For each combination of elevation, aspect, and soil type, three replicate 20m x 20m plots were established, randomly chosen from the acceptable contour points.

Extensions to each permanent plot were formed by four 10m radius circles centered on each plot corner. In each of these four circles, three of the four quadrants fell outside the 20m x 20m plot. In these extensions only spruce trees were sampled. On each plot, all trees over 5cm dbh were permanently marked, measured, and recorded as live or dead. For live spruce (plots and extensions) and fir (plots only), crown condition was recorded as the estimated percentage of recent needle loss from the live crown. Recent needle loss was judged to have occurred where fine twigs and/or brown needles were present. Three classifications were used. If recent needle loss was estimated as less than 10%, a tree was recorded as Class 1, 10-50% was recorded as Class 2, and 50-99% as Class 3. Other, detailed data were recorded but not reported here. Soils were sampled adjacent to all permanent plots (Huntington and Ryan 1988). Non-destructive observations of signs and symptoms of insects and pathogens were recorded on the plots. Destructive branch and root samples were taken around plots, outside a buffer area.

An extensive survey with 130 permanent plots on randomly located transects has also been completed, but the results of the extensive survey have not yet been analyzed.

Growth Rates

We began an intensive study of growth and dendroclimatology in 1987. We will evaluate growth patterns on the mountain in relation to climate as well as topographic location and other site characteristics. We will then be in a position to test for the existence and pattern of growth decline in red spruce on Mt. Moosilauke, and to analyze such patterns for evidence of any non-anthropogenic effects.

We cored red spruce and balsam fir on six sites stratified by the same elevation (three) and aspect (east and west) criteria as the permanent plots. Locations with high densities of multiple age class red spruce were favored. At each site, 20 red spruce and 10 balsam fir were cored, and sapwood extent in each core measured. All trees were mapped, and height, diameter, crown size and shape, and decline class were recorded. Soil depth was measured, and soil typed categorized around each tree, for future comparative purposes.

We are now crossdating the cores before measuring, because of the tendency of red spruce to produce incomplete growth rings or none at all when under stress. Ring width measurements are not yet available, but we have some preliminary observations on recent growth rates. We defined recent growth rate decline as a narrowing of the last 20 to 30 rings, either gradually over 10 or more years, or abruptly changing from wide to narrow rings in one or two years.

Analysis of Trends

Statistical analyses of the vegetation data are not yet complete, with the exception of the sapwood area data. Most results will be presented simply as mean values. Because no estimates of variability are given, the results should be interpreted with caution. Most trends reported in this paper are apparent trends, and may or may not be supported statistically. However, when there is no apparent trend in the mean values, statistical analyses are unlikely to show strong differences. All statements should be regarded as preliminary because of these qualifications.

Results

Standing Dead

For spruce and fir on the permanent plots, the percentages of standing dead individuals are shown in Fig. 1. The percent dead spruce on the east facing slope averages 34% and changes little with elevation (Fig. 1a). On the west slope, a mean of 29% of spruce are dead, with a peak in standing dead at middle elevations. For fir on the east slope, standing dead average only 17%, and the percent dead decreases with elevation. The percent standing dead fir is similar on the west slope, at 16%, but, as for spruce, there appears to be a peak in standing dead at middle elevations. Overall, then, the percent dead spruce is about double that for fir. For each species, the percent dead is similar on both east and west aspects, but the trend with elevation appears different on the east versus the west facing slopes.

The percent of basal area dead for fir (Figs. 2a,b) follows similar trends to the data on percent dead individuals. For spruce, the percent basal area dead is less than the percent dead individuals on the east facing plots, especially at low elevation, and on the low elevation west facing plots. In those strata, the mortality of spruce is concentrated more in the smaller size classes. Because of this, the percent basal area dead is actually higher for fir than for spruce at low elevations on both aspects.

Because permanent plots were placed on both soil types at middle elevations, standing dead spruce and fir can be compared between soil types (Figs. 3,4). For spruce on the east side, both percent individuals dead and percent basal area dead are much higher on the cryofolists than on the spodosols (Fig. 3a and Fig. 4a). On the west side, however, there was no apparent relation between soil type and the proportion of standing dead spruce.

For fir, the percent dead individuals was similar on the two soil types for both east and west aspects (Fig. 3b). On the east side, percent basal area dead followed the same pattern as percent dead individuals, suggesting that all size classes were similarly affected. On the west side, the percent basal area dead was much higher on cryofolists than on spodosols, even though the percent dead individuals was similar on both soil types, indicating that the dead fir on the cryofolists were mainly large trees. In summary, there appear to be differences in forest condition on the two soil types, but the patterns are not consistent. Overall, there are more standing dead on cryofolists than on spodosols, but this difference occurs only on the east side for spruce and only on the west side for fir.

Crown Condition

Crown condition of spruce is shown in Figs. 5a,b. On the east side, crown condition appears worst at low elevations, where 34% of live trees were in decline class 3, and best at middle elevations, where only 10% are in this class. On the west facing slope, the elevational trend is quite different. The low elevation trees have the best crown condition (59% in class 1 and 3% in class 3. At high elevation, 25% are in class 1 and 15% are in class 3. There is little difference in crown condition between middle and high

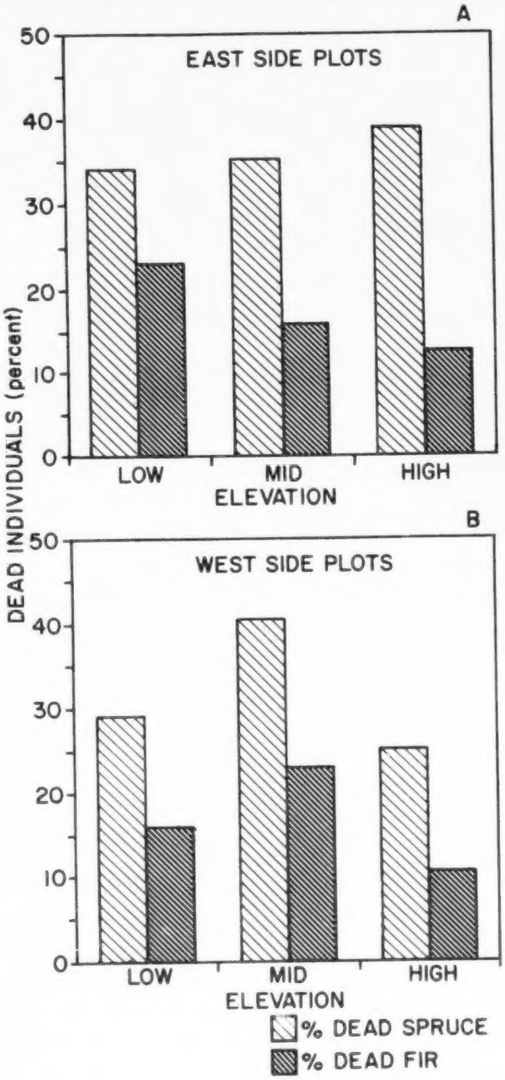

Figure 1.--Percent dead trees for red spruce and balsam fir at low (840m) middle (990m) and high (1140m) elevations on permanent intensive plots. Each value is the mean percentage of all standing trees of that species over 5cm dbh that were dead. At low elevations, means were taken over three plots on spodosols. At high elevations, means were taken over three cryofolist plots. At middle elevations, means were taken over three spodosol and three cryofolist plots. Fig. 1a: east facing slopes. Fig. 1b: west facing slopes.

elevations on the west side. Taking the east and west sides together, there is little overall trend with elevation. However crown condition is better on the west than on the east side at low elevations.

The crown condition of fir (Figs. 6a,b) is generally better than that of spruce. Overall, an average of 17% of spruce are in decline class 3, compared to only 6% for fir. There is no apparent elevational trend, but fir crown condition is better on the west than on the east side at all elevations.

Growth Rates and Sapwood Area Indices

Over the 6 tree core sampling sites, 21 to 48% of spruce show no recent growth decline, 12 to 52% show gradual decline, and 12 to 39% show an abrupt decrease in ring width (Figure 7a). At all elevations, there are more spruce with some recent decline

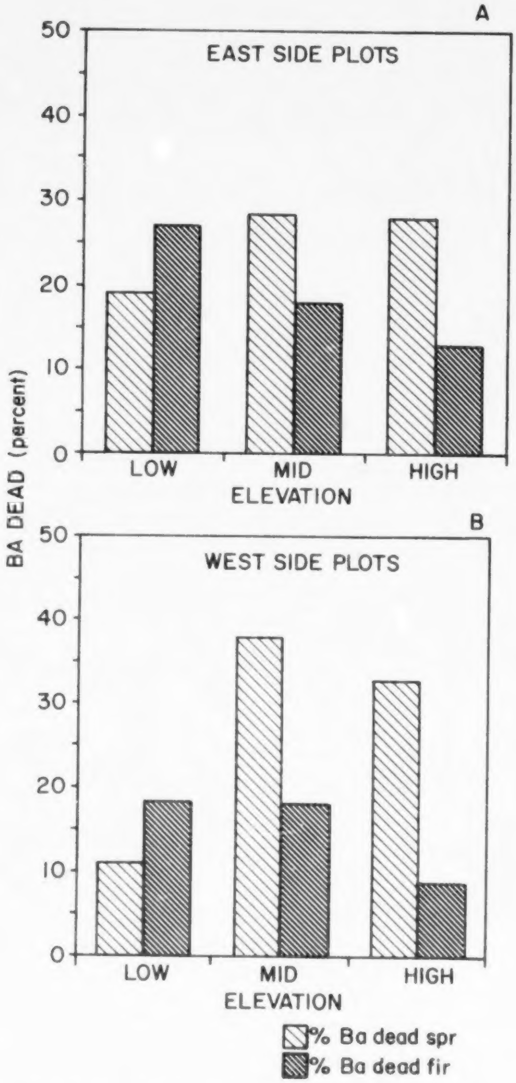

Figure 2.--Percent basal area dead for red spruce and balsam fir. Each value is the mean percentage of total standing basal area of that species that was dead. Elevations sampled and calculation of means are as in Fig. 1. Fig 2a: east facing slopes. Fig. 2b: west facing slopes.

on the east than the west side. The most striking difference occurs between the east and west high elevation sites, where a gradual decline exists in 47% of the east side spruce and 12% of the west, but an abrupt decline occurs in only 12% of the east side spruce and in 39% on the west side. There are no significant differences in red spruce sapwood area indices among sites (ANOVA, $p=0.19$, $df=117$); (Figure 8).

In contrast to spruce, very few fir at the same sites exhibit a recent abrupt growth decline and most show no decline at all, except for fir at the high elevation east side site (Figure 7b). Sapwood area indices for fir are significantly different among sites (ANOVA, $p=0.04$, $df=59$). However, this may be due to the higher values at the low elevation west side site. There are no significant differences between fir and spruce sapwood indices (ANOVA, $p=0.62$, $df=29$) except at the anomalous low elevation west side site (ANOVA, $p=0.008$, $df=29$); (Figure 8).

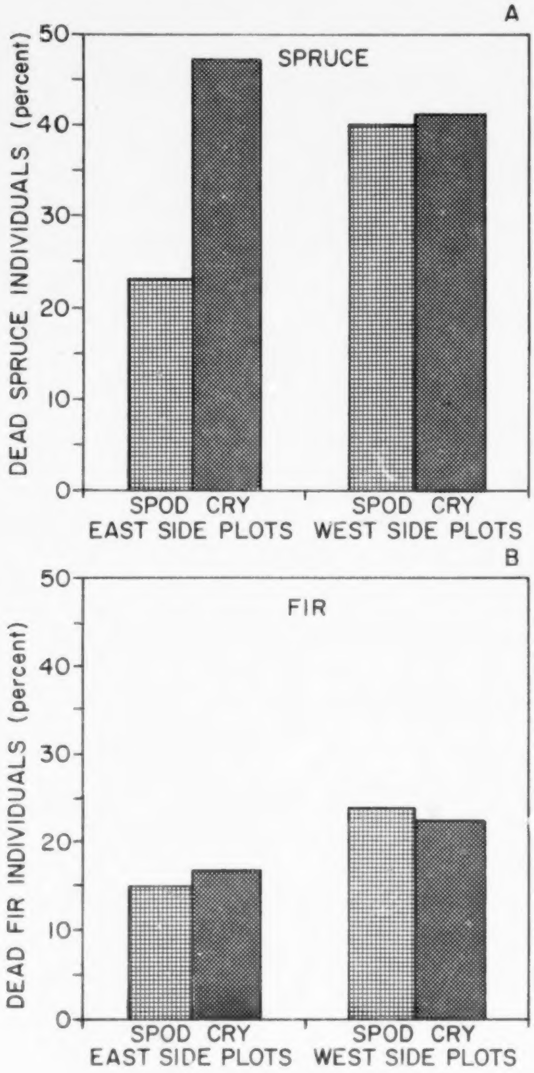

Figure 3.--Percent dead red spruce and balsam fir on spodosols compared to cryofolist soils at middle elevation (990m). Each mean is over three plots. Fig. 3a: red spruce. Fig. 3b: balsam fir.

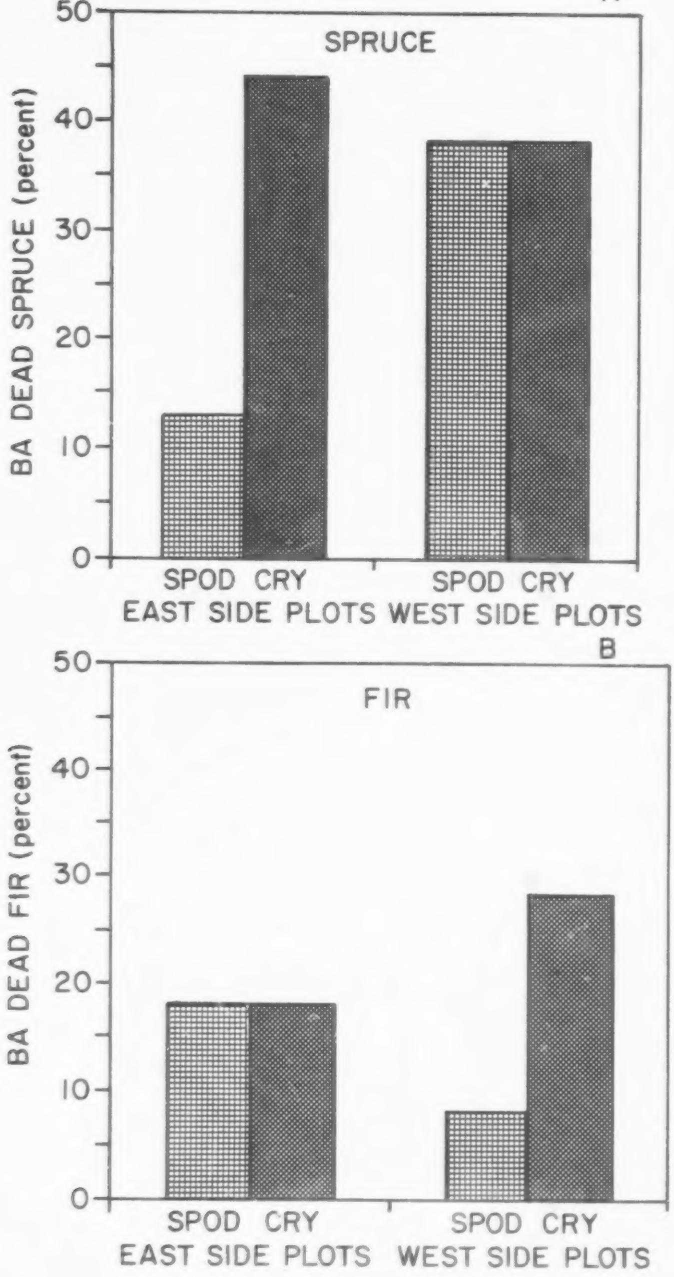

Figure 4.--Percent basal area dead for red spruce and balsam fir at middle elevation (990m) on spodosols compared to cryofolist soils in permanent intensive plots. Each mean is over three plots. Figs. 4a: red spruce. Fig. 4b: balsam fir.

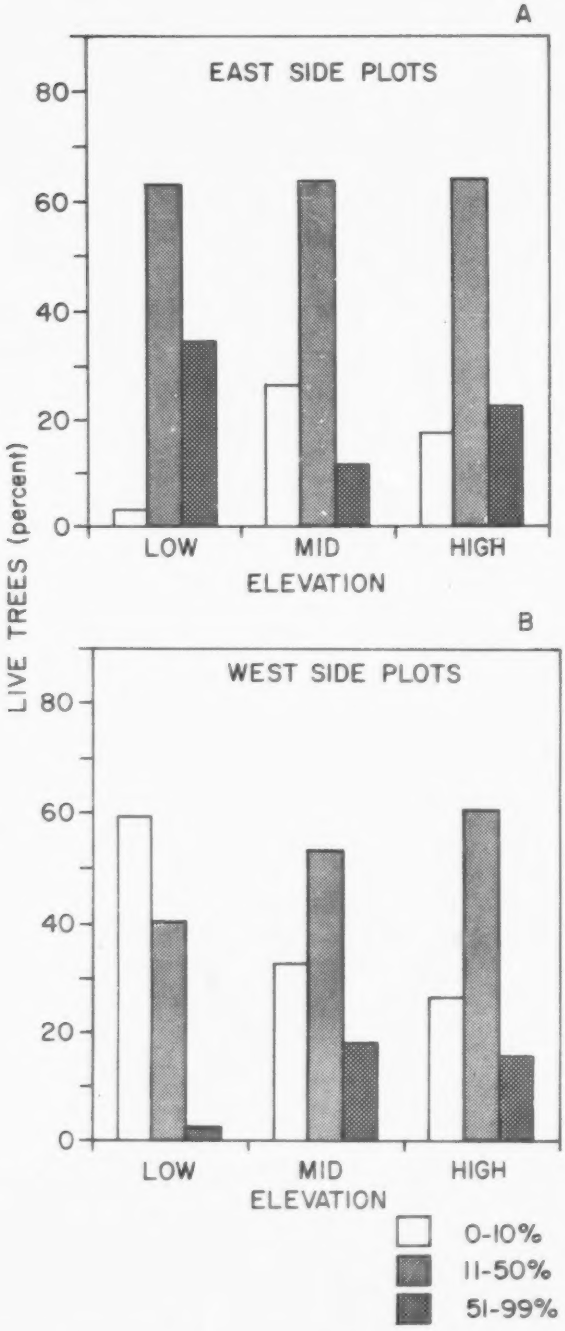

Figure 5.--Percent of live trees in each crown class for red spruce in permanent intensive plots. Elevations and calculations of means are as in Fig. 1. Crown classification is based on estimated percent recent needle loss from the live crown. Fig. 5a: east facing slopes. Fig. 5b: west facing slopes.

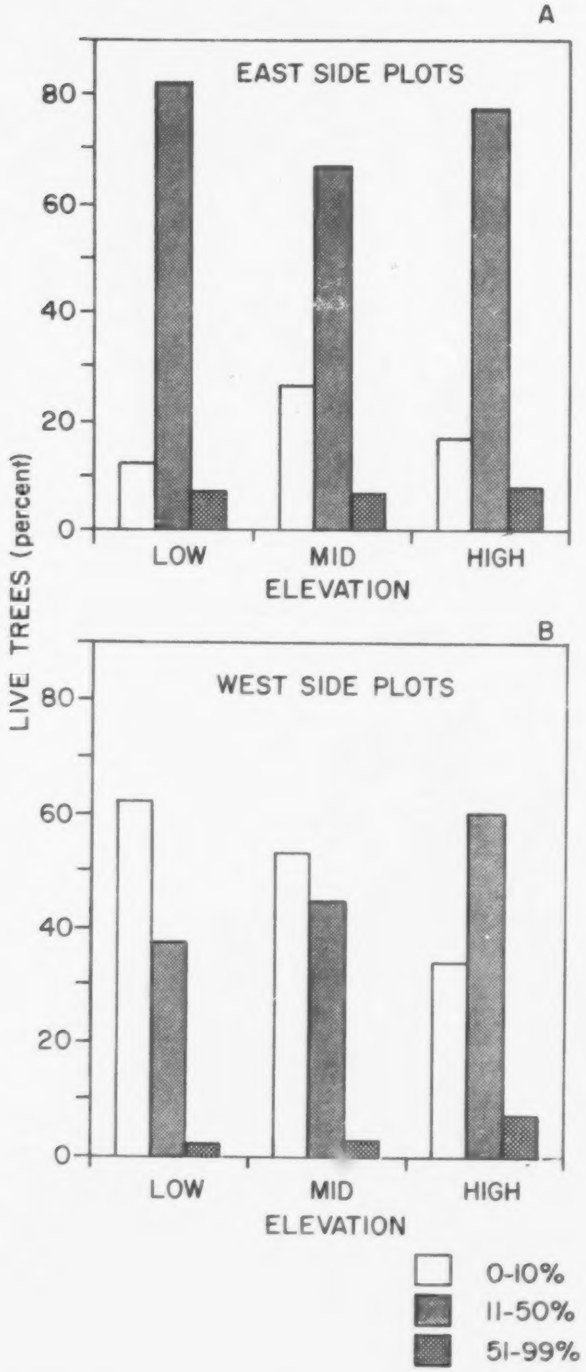

Figure 6.--Percent of live trees in each crown class for balsam fir in permanent intensive plots. Data are presented as in Fig. 5.

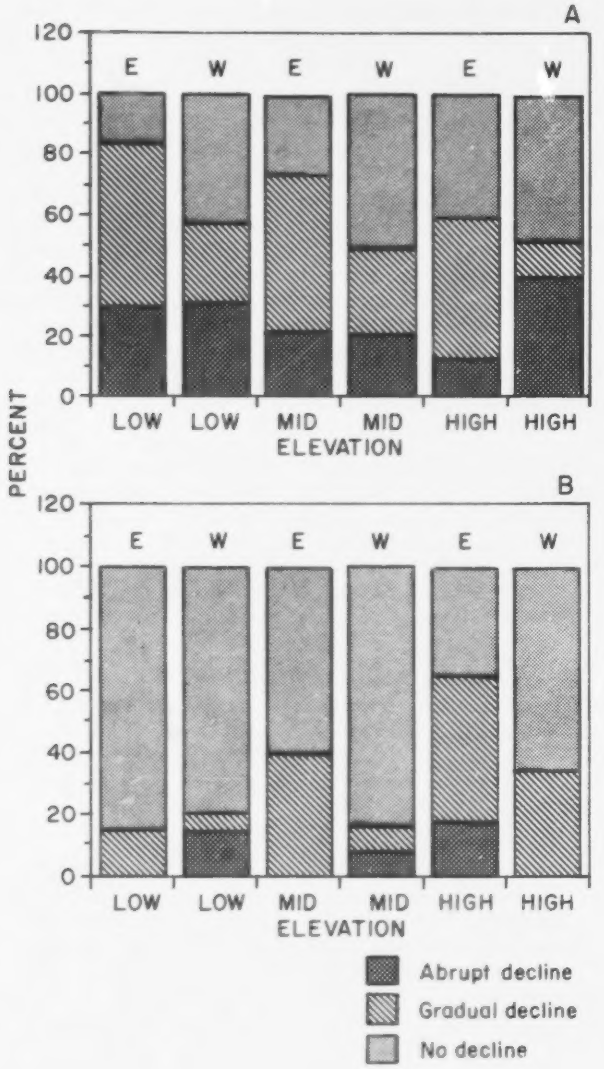

Figure 7.--Recent growth by elevation and aspect. E = east facing slopes, W = west facing slopes. Elevations are as in Fig. 1. For each site, n = 33 to 42 cores. Fig. 7a: red spruce. Fig. 7b: balsam fir.

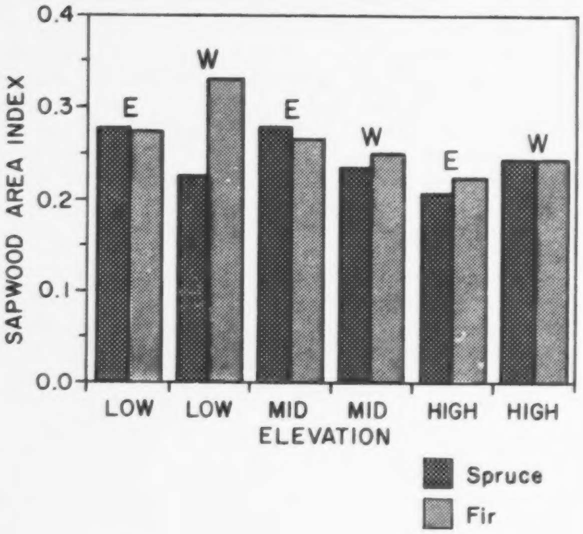

Figure 8.--Mean sapwood area index (sapwood area/basal area) for red spruce and balsam fir by elevation and aspect. E = east facing slopes, W = west facing slopes. Elevations are as in Fig. 1. For each site n = 20 spruce, n = 10 fir.

Insects and Pathogens

We have completed a detailed inventory of the insects at Mt. Moosilauke. Of these, the most likely agent of serious damage to spruce is the ghost moth, *Hepialus gracilis*, whose larvae feed on the roots of several woody and herbaceous species. The ghost moth was found near all but three of our permanent plots with 15 minutes of searching in the forest floor. David Wagner (pers. comm.) has found higher densities of the moth at Moosilauke than at Whiteface Mt. Studies of the ghost moth at Mt. Moosilauke are continuing. Some evidence of balsam woolly adelgid, *Adelges piceae*, damage was found on fir at low elevations. Adult cerambycid feeding on both spruce and fir was common, but we do not consider this to be a major stress on the trees.

The data from our detailed pathogen survey are not yet available, but to date no agent of major damage has been clearly identified. High nematode counts have been found in the low and middle elevation plots sampled to date (from 22,000 to 46,000 per 100g forest floor). The potential for nematode damage will be further investigated.

Discussion

Our preliminary data suggest that the condition of spruce is, by most measures, worse than that of fir at Moosilauke. This difference is apparent in the percent dead and percent basal area dead, the percentage of trees in the least vigorous decline class (class 3), and in the occurrence of recent abrupt or gradual decline. However there was no significant difference between spruce and fir in sapwood area index. It is also important to note that the percent standing dead is not a measure of mortality rate. If spruce stand longer after death than fir, a greater percentage of standing dead trees would be expected for spruce than for fir, even if the mortality rates were identical. We do not yet have enough information on the rate of fall of dead trees to adjust percent standing dead to a corrected mortality rate.

The beginning of the abrupt decline in the red spruce cores does not appear synchronous: starting dates vary from 1954-1980. More precise dating and measurements of the cores will enable us to define spatial patterns of recent growth decline on Mt. Moosilauke, and to test whether this site fits with the reported regionally synchronous, abrupt growth decline of high elevation red spruce.

Overall, the results do not show clear and consistent trends in forest condition with elevation and aspect. Our results differ from those at Whiteface Mt., where the percent standing dead spruce increases from about 30% at comparable low elevations to 50-70% at high elevations (Johnson and Battles, unpub. data), compared to an overall mean of about 33% at Moosilauke. Strong aspect differences were not found at Whiteface, except for a higher percent standing dead spruce on the northwest facing slope. The percent standing dead was not related to aspect at Moosilauke for spruce or fir. However crown condition of both spruce and fir is better on the west than the east facing slopes at Moosilauke. It is possible that both spruce-fir forest condition and atmospheric deposition vary systematically from east to west on a larger scale across the northeast, with the worst condition and highest exposure to pollutant effects in the Adirondacks, and the best condition and least exposure in the White mountains and Maine, but we do not yet have adequate data to rigorously evaluate this hypothesis.

We have observed that the occurrence of standing dead trees is patchy at Mt. Moosilauke. It is apparent from the results presented here that much of this variablity is not related to aspect and elevation. Whether forest condition is statistically related to soil type will be clearer when we have examined the extensive transect data. It is surprising to us that spruce and fir condition does not worsen with elevation, because natural stresses, even in the absence of atmospheric deposition effects, tend to incease with elevation. Nevertheless, there are substantial numbers of dead trees on Mt. Moosilauke, especially spruce, and many that show evidence of growth decline. It appears likely that mortality and growth decline are influenced by several factors, that may vary with elevation in different ways.

It is possible that some of the trends observed in the intensive permanent plots may differ from those in the randomly chosen extensive plots. This will be evaluated when the data from the extensive plots have been analyzed. These and other analyses of data already collected will clarify some of the uncertainties about patterns in forest condition at Mt. Moosilauke. Additional research is underway on several fronts.

Acknowledgments

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Instrumentation for Obtaining Meteorological and Precipitation Information at Multiple Remote Forest Sites

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Abstract

In response to needs for basic meteorological and precipitation data at multiple forest sites where electricity was not available, we have designed and field tested a portable meteorological unit (PMU). The unit can be carried by two people and erected in a few hours. A virtually continuous record of wind speed and direction, temperature, relative humidity, solar radiation, rainfall and intercepted cloud water are retained in a battery powered data logger which is manually interrogated at ten day intervals with a tape recorder. The total cost of each unit is less than $2500.

Instrument Design

Mt. Moosilauke (1465 m) in the southern White Mountains of New Hampshire is a research site in the Spruce Fir Research Cooperative (SFRC) of the National Acid Precipitation Assessment Program (NAPAP). Permanent vegetation study plots have been established on the mountain, stratified by elevation (840m, 990m, 1140m), aspect (E and W), and soil type (haplorthods and cryofolists). Detailed data covering meteorological information, rain and cloud deposition and chemistry, and atmospheric chemistry are available from our Mountain Cloud Chemistry Program (MCCP) site located on a 975m knoll about 4 km from the main summit.

In order to obtain more detailed micrometeorological data and precipitation information specific to the permanent study plots, we have designed and field tested a network of battery powered and easily deployable stations called Portable Meteorological Units (PMU's). Because we wished to deploy a minimum of seven such stations, our design considerations included ease of deployment, ease of service and data collection, and cost.

The design is based on the recently released Campbell CR-10 data logger, which has certain features which are particularly desirable for ths application. Specifically, the CR-10 is housed in a sealed metal case with only simple pin connections exposed. Power source, terminal connections and provision for keypad, telephone or radio input and output are all external. For our application, a single keypad and tape recorder are used to program and interrogate the entire network. We opted to add an extra 64K memory module to each unit, which allows us to accumulate data for 10 to 14 days and then to dump data manually into a tape recorder.

A schematic illustration of the typical PMU is given in Fig. 1, and a detailed component list in Table 1. Additional Information about the components is given below.

The Campbell Scientific CR-10 Measurement and Control Module has 12 single ended analog inputs, 2 pulse counting inputs, 3 switched excitation outputs, and 8 digital I/O ports which provide on/off control or binary inputs. Resolution of the analog inputs is 13 bits of five full scale ranges to 2.5 mv full scale, and any pair of inputs can be used for differential measurements. The pulse counting inputs can be used up to 250 KHz. Excitation voltages can be AC or DC and are adjustable anywhere in the range of plus or minus 5 volts. Power requirement is 12 volts and standby current is 0.5 ma. The CR-10 instruction set is quite flexible, with an internal clock, provision for thermistor, thermocouple and platinum resistance thermometer measurements, curve fitting, histogram and other elementary data processing operations before storage. Internal memory stores up to 5300 data values. We have added an external 64K RAM module which increases this to approximastely 16,000 data values. We have also used the standard accessory Campbell wiring harness and the plug-in keypad. We have housed the CR-10, lantern battery power supply, and the CR-10WP wiring panel in a small rubber gasket sealed metal box, such as is available from Edmund Scientific Corporation.

For wind speed and direction we have chosen the R.M. Young model 03001-5 Wind Sentry combined Anemometer and Vane. The unit is pictured, with specifications, in Fig. 2.

Table 1.--Component list for Portable Meteorological Units and suppliers

Instrument	Model #	Supplier	Price
			Dollars
Datalogger	CR-10	Campbell Scientific	800
Wiring panel	CR-10WP	Campbell Scientific	190
Key pad	CR-10KD	Campbell Scientific	110
64K memory		Campbell Scientific	50
Annemometer/ wind vane	03001-5	R.M. Young	285
Temp/rel. humid.	207	Campbell Scientific	190
Gill rad. shield	41001	Campbell Scientific	160
Radiometer	LI200S	Campbell Scientific	195
Tape recorder	RC35	Campbell Scientific	95
Interface	SC93	Campbell Scientific	115
Rain gauge	F72, 165	Edmund Scientific	60
Tipping bucket	F72, 319	Edmund Scientific	90
TV mast			70
Miscellaneous			50

Temperature and relatively humidity are measured with a Campbell Scientific Model 207 probe which contains a Phys-Chemical Research PCRC-11 RH sensor and a Fenwal Electronics UUT51J1 thermistor. Accuracy is specified by the manufacturer as 0.2°C, and 5% RH. The unit is mounted with a Campbell Scientific Model 41001 Gill radiation shield.

Solar radiation is monitored by a Campbell Model LI 200S Licor silicon photodiode pyranometer.

Rain is collected by an Edmund Scientific Model F72, 165 tipping bucket rain gauge. Cloud water is collected in a modified passive string collector constructed of 200m of 0.1mm nylon monofilament mounted so as to drain directly into an Edmund Scientific Model F72, 319 tiping bucket gauge. Since the two pulse channels of the CR-10 are used by the anemometer and the rain gauge, a special circuit was constructed which converts the relay closures of the tipping bucket device and stores them as increasing voltage steps which can be read by a voltage channel of the datalogger. A diagram of the rain and cloud collectors and the conversion circuit are given in Figure 3.

Components are mounted on commercially available telescoping television masts which have ten foot sections up to a total of 50 feet. Guy wires are attached at the top of each section and attached to nearby trees or to stakes in the ground. The entire unit can be carried by two people, and installed in a few hours. For regular deployment during the 1988 field season we will place the instrument package about 1 m above the nearby canopy. This was not possible for all sites during the 1986 field tests.

The meteorological instruments are not winter hardy, so that the towers must be lowered and the instruments removed before icing conditions prevail. We intend to leave the dataloggers in the field, however, recording air temperature, soil temperature at several depths, and soil moisture during the winter months. Design specifications indicate that we should be able to accumulate such data for up to eight months with a single set of lantern batteries.

Results of Field Tests

Seven PMU's were deployed during September and October, 1988. Three each were placed on the east and west slopes of the mountain at the same elevation as the permanent plots (840m, 990m, 1140m), and a seventh was placed about 20 m from the

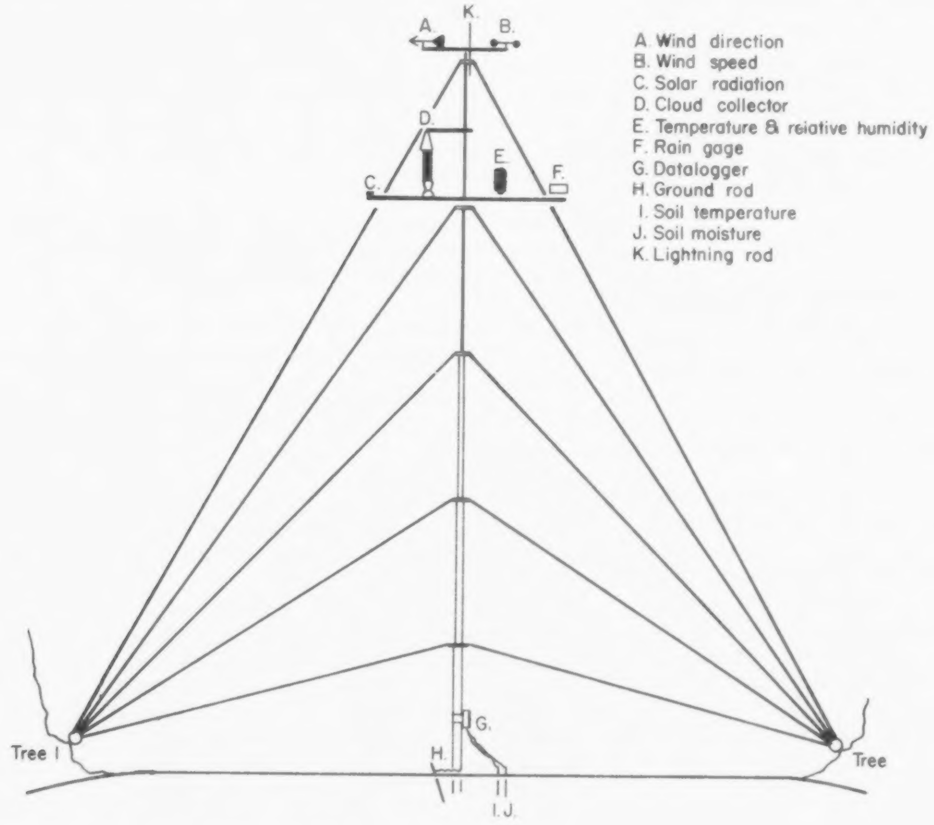


Figure 1.--Schematic of Portable Meteorological Unit (PMU)

MCCP station at 975m. Because of the urgent need to accumulate field exposure time during the limited field season, instrument were placed in the field as received from the manufacturer, without further testing or calibration.

Figure 4 allows comparison of time series data records from the MCCP site and the adjacent PMU for the week of September 13, 1987. Although qualitative agreement is evident, there are obvious quantitative disagreements in the solar radiation and the precipitation data. It was subsequently found that the solar detector of the PMU had been partially obscured by a foreign object during that week, explaining the low readings. The PMU precipitation data for hourly precipitation are about 80% high. Since calibration of the MCCP gauge is checked frequently, it appears that the PMU calibration is seriously in error.

Figures 5 and 6 show time series records of precipitation and cloud water collection from the PMU's located on the mountain. Given the apparent calibration problem of the rain gauge on the PMU at the MCCP site, one should certainly not draw quantitative conclusions from the precipitation data of Fig. 5 until the rain gauges are calibrated. It does appear, however, that aspect and elevational comparisons of precipitation will be possible.

Cloud water data is available for only the mid and upper PMU sites on the east (PMU #'s 1.02 and 1.03), the mid and upper sites on the west (PMU #2.02 and 2.03, and the PMU adjacent to the MCCP site (PMU #3.00), because additional collectors were not available in time for deployment. Since the amount of cloud water deposition is a function of wind speed, collector geometry, and liquid water content of the cloud, the amount of water collected by the string collector is only a rough measure of cloud water deposition into the forestry canopy, but the duration of cloud events should be accurately recorded by the collectors. The data of Fig. 6 suggest, quite reasonably, that the duration of cloud events is higher at the high elevation sites than at the mid elevation sites, and it appears that for the cloud event of Julian days 262 to 264 the eastern high elevation site and the MCCP site had substantially greater cloud water deposition than the other sites.

In conclusion we find that it is practical to obtain meteorological and precipitation data from remote forest sites. Both absolute and relative calibrations of the units are needed at the beginning and end of the field season; some periodic spot checks during the season would be highly desirable.

Acknowledgment

We wish to acknowledge support from the Environmental Protection Agency under the Mountain Cloud Chemistry Project, and support from the United States Forest Service under the Spruce Fir Research Cooperative program, which together made this work possible.

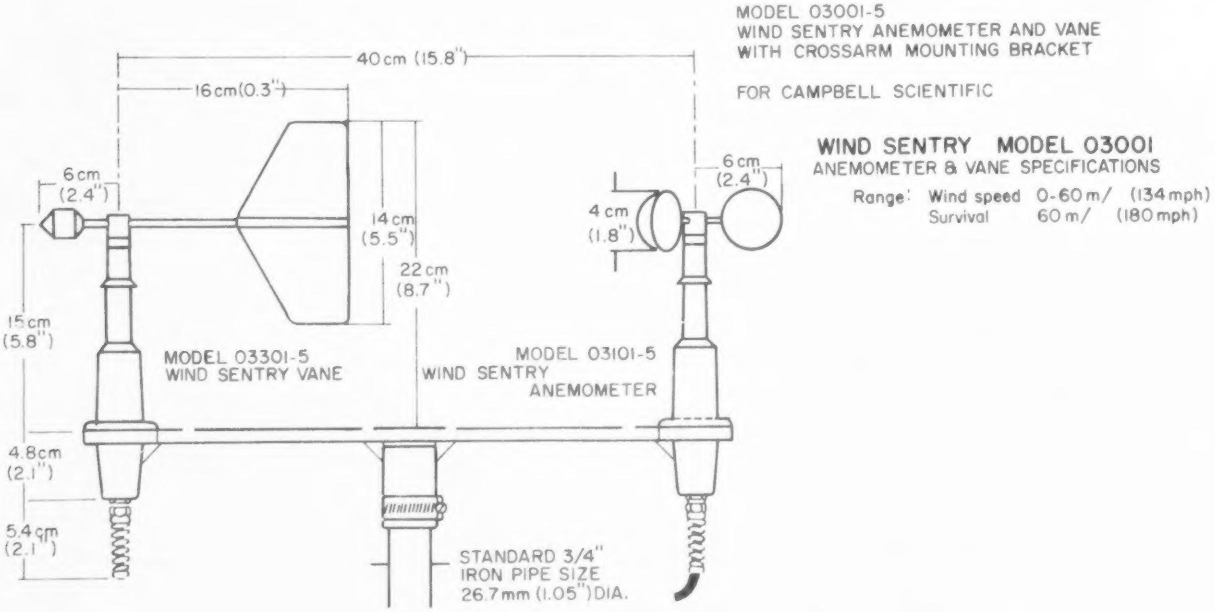
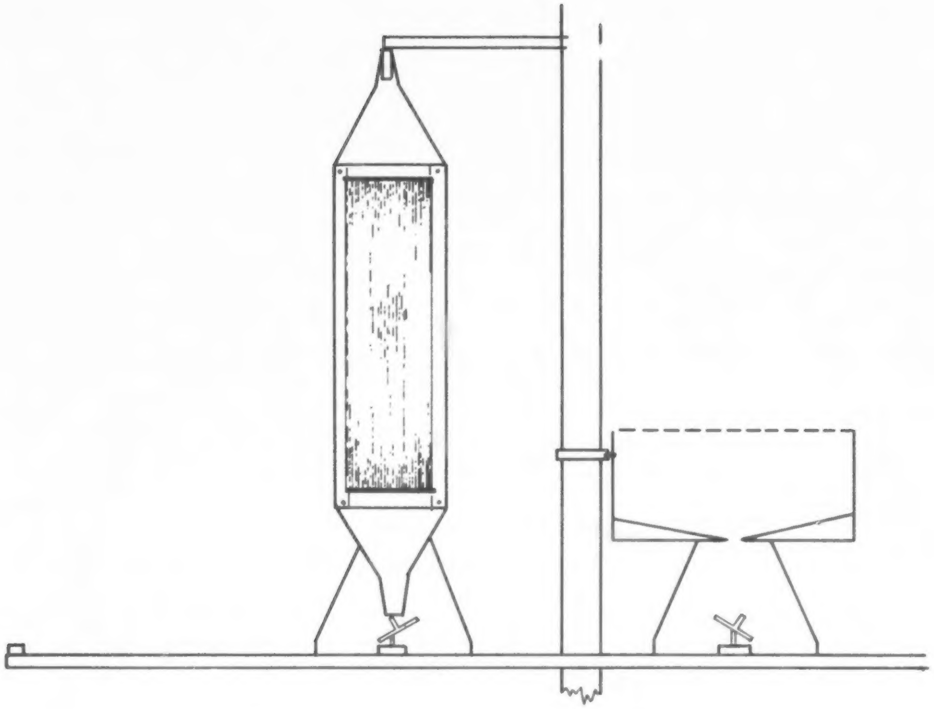

MODEL 03001-5
WIND SENTRY ANEMOMETER AND VANE
WITH CROSSARM MOUNTING BRACKET
FOR CAMPBELL SCIENTIFIC
WIND SENTRY MODEL 03001
ANEMOMETER & VANE SPECIFICATIONS
Range: Wind speed 0-60 m/ (134 mph)
Survival 60 m/ (180 mph)
40 cm (15.8")
16 cm (0.3")
6 cm (2.4")
14 cm (5.5")
22 cm (8.7")
4 cm (1.8")
6 cm (2.4")
15 cm (5.8")
MODEL 03301-5
WIND SENTRY VANE
MODEL 03101-5
WIND SENTRY
ANEMOMETER
4.8 cm (2.1")
5.4 cm (2.1")
STANDARD 3/4"
IRON PIPE SIZE
26.7 mm (1.05") DIA.

Figure 2.--R.M. Young Wind Sentry anemometer and wind vane



CONNECTING THE CLOUD COLLECTER TO THE CRIO DATALOGGER

The circuit diagrammed below takes the relay closures at the cloud collector and turns them into increasing voltage steps which can be read by a voltage channel on the datalogger. This is necessary due to the fact that the datalogger has only two pulse channels: One for the anemometer and one for the rain gage.

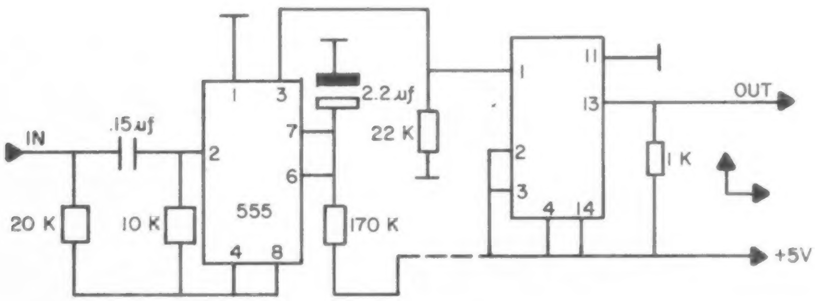

IN
.15 µf
20 K
10 K
555
1
3
7
2
6
4
8
2.2 µf
22 K
170 K
11
13
1
2
3
4
14
OUT
1 K
+5V

Figure 3.--Passive string cloud-water collector and conversion circuit

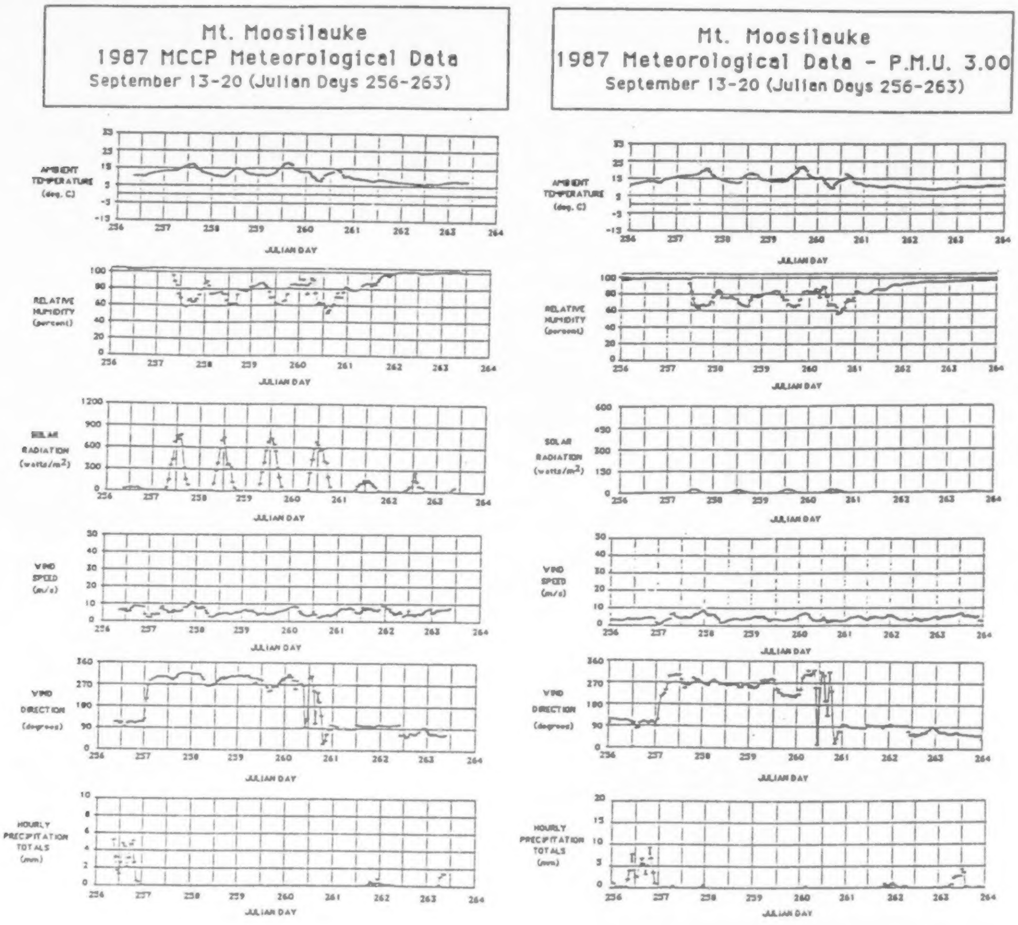


Figure 4.--Time series of meteorological and precipitation data collected at the MCCP station and nearby PMU #3.00

Mt Moosilauke 1987 P.M.U. Meteorological Data

September 11-22 Cloud Tips (# tips) Page 1 of 1

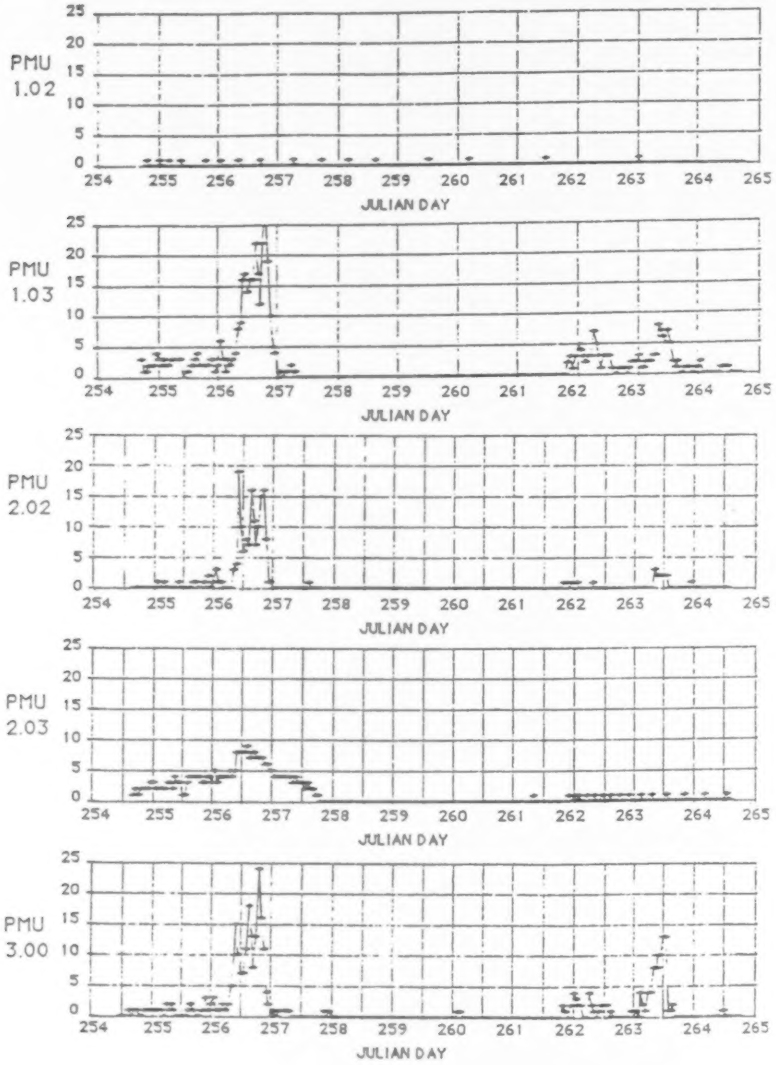


Figure 5.--Time series data of precipitation data collected at PMU's. Units 1.01, 1.02, and 1.03 are at low, medium, and high elevations on the east aspect. Units 2.0x are at corresponding locations on the west slope, and 3.00 is adjacent to the MCCP station.

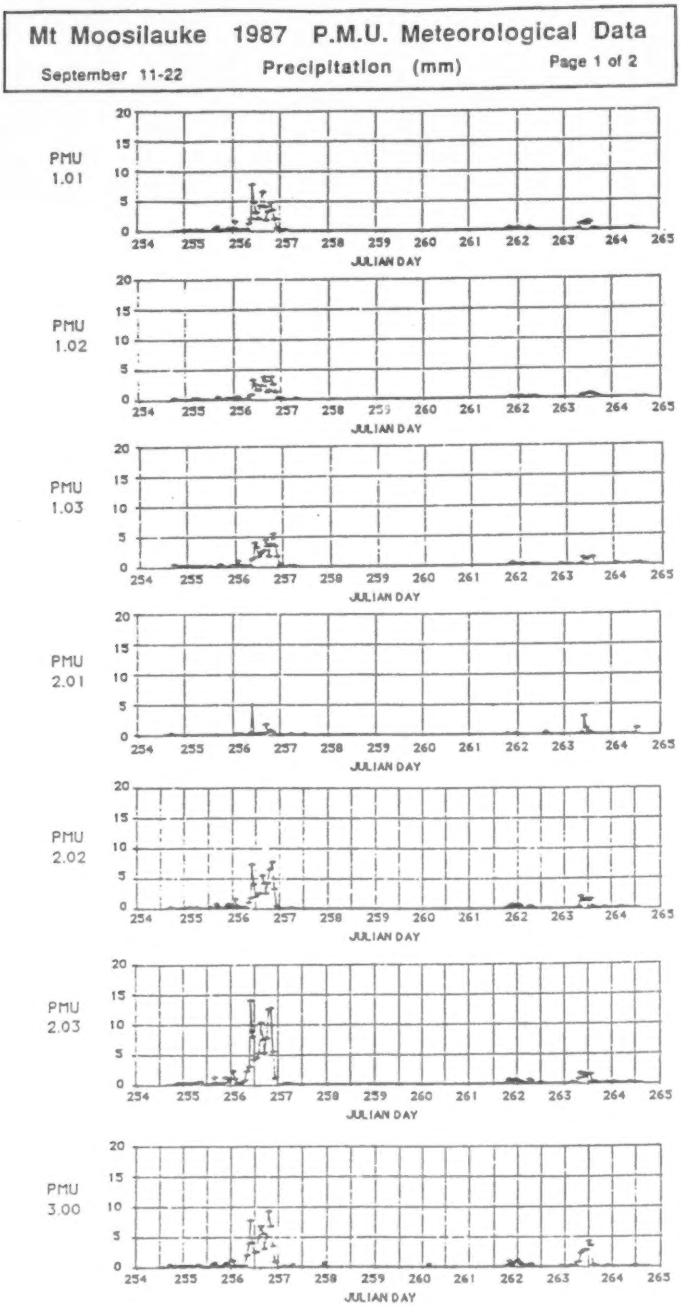


Figure 6.--Time series data of cloud water collected at PMU's. Units numbered as in Figure 5.

Soil Chemical Properties in the Spruce-Fir Zone on Mount Moosilauke in New Hampshire

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University of Pennsylvania, Philadelphia, PA 19118

Abstract

As part of an integrated forest response study on the influence of S and N derived pollutants on red spruce and balsam fir, this report summarizes a preliminary soil chemical characterization. The principle mechanisms by which atmospheric deposition are related to forest decline are cation depletion, A1 and trace metal toxicity and nutrient imbalances. Soil chemical properties such as pH, exchangeable cations, extractable metals, extractable P, and organic matter are reported. Exchangeable cations are reported as concentrations and as nutrient pool sizes. At higher elevations, shallow organic soils predominate which in general have smaller nutrient pool sizes and higher concentrations of A1 and lower concentrations of extractable bases than the mineral soils predominating at lower elevations.

Introduction

In order to better understand the influence of the deposition of atmospheric pollutants associated with compounds of S and N on tree growth and mortality in high elevation spruce-fir forests we have initiated an integrated forest response study on Mt. Moosilauke in New Hampshire. In this report we summarize preliminary soil chemical characterization and nutrient status.

The primary questions involving soils are what are the effects of S and N derived pollutants on red spruce and balsam fir through mechanisms of nutrient cation leaching, mobilization of metals, complexation of P, and N dynamics.

Natural soil acidification may be accelerated by deposition of hydrogen ions and hydrolysis of A1 which increases displacement of cations from the exchange complex and leaching loss (Bockneim 1983, Ulrich 1983, Cornan and Schofield 1979). Tree growth may ultimately be effected by nutrient depletion or unfavorable element ratios (such as Ca/A1, P/A1, N/Ca or N/P).

Soil acidification increases the solubility (mobilizes) A1 (Cronan and Schofield 1979, Ulrich 1980) and trace metals. Elevated concentrations of soil solution A1 and low Ca/A1 ratios are believed to effect trees by inhibition of root function (McLaughlin 1985) and root growth (Schier 1985).

Trace metal concentrations may be increased directly by atmospheric deposition or indirectly by increased acidification which increases metal solubility in the process known as mobilization. Gradients in metal (Pb, Zn and Cu) concentrations have been observed along elevation gradients (Reiners et al. 1979, Friedland et al. 1984). Soil acidificaiton may also result in reduced availability of P to plants (Rorison 1980).

Forest mineral nutrition is influenced by numerous interacting variables. Our ultimate objective is to determine whether S and N derived pollutants effect tree growth to an extent which is distinguishable from the underlying variability attributable natural factors such as climate, pests and pathogens and interspecific competition.

Methods

The study area is between 840 and 1200 m elevation on the Eastern slopes of Mt. Moosilauke in the White Mountains of North-Central New Hampshire. The forest is second growth and composed primarily of balsam fir *(Abies balsamea)* paper birch *(Betula papyrifera)* and red spruce *(Picea rubens)*. Species such as maple *(Acer saccharum)*, beech *(Faqus grandifolia)* and ash (*Fraccinus americana*) are important only at the lowest elevation. The forest is of variable age depending upon the date of last disturbance. Within the last 70 years most of the study area was either logged or suffered extensive hurricane damage.

Extensive transects were used to characterize the general distribution of forest and soil types. We chose a stratified random experimental design using three elevations and two predominant soil types to sample soils intensively at sites paired with permanent vegetation plots. To sample soils we excavated pits quantitatively in order to permit calculation of element pool sizes.

Selection of permanent plots and adjacent soil sampling locations was based upon extensive transects along three elevation contours (840, 1000 and 1200 m). Potential plot centers were systematically evaluated based upon criteria which included forest composition, soil type and slope. Three points were randomly chosen for each soil/elevation category from the pool of points satisfying the selection criteria.

We identified two soil types which we nominally referred to as spodosols and cryofolists. In the spodosol category we included more pooly drained soils, probably inceptisols, which occur together with spodosols. What we have termed cryofolists are typified by shallow organic soil mats overlying thin lenses or perched pockets of mineral soil which rest on very coarse bouldery till or ledge. Taxonomically, only those organic soils underlain by ledge or bedrock are folists because the depth of the till is generally much greater than four inches. Functionally we view these soils as folists because the nature of the till is such that it does not provide an effective rooting medium. In most cases these organic soils are underlain by a complex network of boulders often interspersed with large voids and with very little mineral material which is < 2 mm.

The protocol for distinguishing soil types was to make 20 probings with a soil corer along perpendicular axes at each potential

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sampling location. We evaluated the relative proportion of organic to mineral soil volume in each core. If ⅔ or more of the volume was organic then the core was classified as a cryofolist. If less than ⅔ of the volume was organic then the core was classified as a spodosol. We found that the scale of spatial variability for soil types could be as small as a few meters and that in general a complex mosiac of the two soil types existed.

A soil survey was conducted along the three elevation contours which involved probing to evaluate 20 cores at 135 locations over 9 km. All cores which did not contact rock within 3 cm were classified as cryofolist or spodosol. The proportion of cryofolist and spodosol cores at each location was calculated and means were obtained for each elevation.

The procedures used for soil sampling have been described by Huntington et al. (1988). In spodosols a square pit (0.71 X 0.71 m) was excavated adjacent to each vegetation plot. The forest floor was excavated in two separate samples, the combined Oi + Oe horizons and the Oa horizon. The mineral soil was excavated in three depth strata designated nominally as 0-10, 10-20 and 20 + cm (20 cm to the bottom of the B horizon). All material removed from the pit was sieved and weighed to permit calculation of soil mass, rock volume and bulk density.

Samples from genetic horizons were collected from the pit faces. On cryofolists soils, four pits were excavated adjacent to each vegetation plot. In these cryofolist pits the forest floor was excavated as described for spodosol sites but the mineral soil was removed quantitatively as one single sample.

Analytical procedures followed closely those described in the Technical Manual of Laboratory Methods (Robarge and Fernandez, 1985). Exchangeable cations were extracted with 1 N NH_4Cl. "Available" P was extracted with the Bray-1 extractant. Metals were extracted with 0.1 N HCl. Sample extracts were analyzed by ICP mass spectrometry at the Institute of Ecology in Athens, Georgia. Organic matter was estimated by loss on ignition where samples were ashed for three hrs at 500 °C. Concentrations of exchangeable cations are reported as centimoles of positive charge for a given element per kilogram oven dry soil, e.g. cmole +Ca/kg.

The distinction between Oa and mineral soil was based on a field estimation of soil organic matter concentration in which soil with > 40% organic matter was included as Oa and soil with < 40% organic matter was included in the 0-10 cm stratum.

Results and Discussion

Concentrations of Exchangeable Cations and Extractable Metals

The extensive soil probing survey indicated that the proportion of cryofolist surface area increased with increasing elevation from 30% at 840 m to 61% at 1200 m (Table 1). The proportion of surface area in which rock was encountered within 3 cm ranged between 10 and 16% and did not vary consistently with elevation.

Table 1.--Percentage of total surface area occupied by cryofolists, spodosols, and rock, by elevation, on eastern slope of Mt. Moosilauke

Elevation (m)	Cryofolist[a]	Spodosol[a]	Rock
840	30	70	16
1000	41	59	10
1200	61	39	13

[a] Percentage of total surface area where rock was not encountered within 3 cm of the surface.

In general the concentrations of 1 N NH_4Cl exchangeable Ca and Mg declined with increasing elevation within a given soil type both in the forest floor and in the mineral soil (Tables 2 and 3). The concentrations of Ca and Mg were nearly twice as high in the forest floor and mineral soil depth strata in spodosols at 840 than at 1000 m elevation. The same trend is true for K in the forest floor but not in the mineral soil (Table 4). Concentrations of the base cations in the cryofolist soils are generally lower than those found in the low elevation spodosols but similar to the top 10 cm of mineral soil in spodosols at 1000 m.

The concentration of exchangeable Al generally increased with elevation. Both cryofolists and spodosols above 840 m have higher concentrations of exchangeable Al than the spodosols at 840 m but there is little difference between elevations on the cryofolist soils (Table 5). The importance of both exchangeable Al and exchangeable Ca to productivity of spruce-fir forests has been demonstrated by Fernandez and Struchtemeyer (1985) in eastern Maine.

We expected that the concentrations of extractable metal ions would increase with increasing elevation for two reasons. It is thought that pollutant loading of metals in both wet and dry deposition (including cloudwater) increases with increasing elevation (Reiners et al. 1975, Friedland et al. 1984). A similar depositional gradient for acidic compounds would suggest that at higher elevations soils would be more acidified resulting in a great solubility of potentially toxic metal ions. Our preliminary results do not generally support this hypothesis in the case of Mn, Pb and Zn (Tables 6, 7 and 8). There are instances where metals did increase with elevation; for example, in a comparison of Zn concentrations in cryofolists at high elevations vs spodosols or in a comparison of Pb concentrations in all soil horizons between the spodosols at 840 and 1000 m.

The concentrations of exchangeable cations measured for soil horizons sampled from pit faces were highest in the Bh and declined with depth in the Bs horizons (Table 9). Concentrations of Ca and Mg were lower at 1000 m than at 840 m elevation. For K and Al the opposite trend was observed.

Table 2.--Concentration of exchangeable calcium by elevation, soil type and horizon or mineral soil depth strata

Elevation (m)	Soil type	Oie	Oa	Depth strata (cm) 0-10	10-20	20 +	Mineral soil total
		-------------cmole + Ca kg^{-1}-------------					
840	Spodosol	17	5.1	0.89	0.48	0.33	
1000	Spodosol	6.1	3.0	0.35	0.23	0.13	
1000	Cryofolist	9.8	5.3				0.42
1200	Cryofolist	7.9	4.2				0.22

Table 3.--Concentration of exchangeable magnesium by elevation, soil type and horizon or mineral soil depth strata

Elevation (m)	Soil type	Oie	Oa	Depth strata (cm) 0-10	10-20	20 +	Mineral soil total
		-------------cmole + Mg kg^{-1}-------------					
840	Spodosol	4.4	1.6	0.32	0.16	0.12	
1000	Spodosol	1.2	0.60	0.19	0.15	0.04	
1000	Cryofolist	1.7	1.1				0.22
1200	Cryofolist	1.5	1.0				0.17

Table 4.--Concentration of exchangeable potassium by elevation, soil type and horizon or mineral soil depth strata

Elevation (m)	Soil type	Oie	Oa	Depth strata (cm) 0-10	10-20	20 +	Mineral soil total
		-------------cmole + K kg^{-1}-------------					
840	Spodosol	2.2	0.9	0.16	0.09	0.07	
1000	Spodosol	1.1	0.62	0.19	0.13	0.06	
1000	Cryofolist	1.4	0.66				0.19
1200	Cryofolist	1.7	0.60				0.15

Table 5.--Concentration of exchangeable aluminum by elevation, soil type and horizon or mineral soil depth strata

Elevation (m)	Soil type	Oie	Oa	Depth strata (cm)			Mineral soil total
				0-10	10-20	20+	
		cmole + Al kg^{-1}					
840	Spodosol	0.20	6.8	8.6	4.5	3.1	
1000	Spodosol	7.2	16	9.49	7.33	4.1	
1000	Cryofolist	3.1	9.8				11.3
1200	Cryofolist	4.1	8.2				8.2

Table 6.--Concentration of extractable manganese by elevation, soil type and horizon or mineral soil depth strata

Elevation (m)	Soil type	Oie	Oa	Depth strata (cm)			Mineral soil total
				0-10	10-20	20+	
		mg Mn kg^{-1}					
840	Spodosol	849	109	53	93	34	
1000	Spodosol	193	42	9.0	11	36	
1000	Cryofolist	808	65				7.7
1200	Cryofolist	195	43				28

Table 7.--Concentration of extractable lead by elevation, soil type and horizon or mineral soil depth strata

Elevation (m)	Soil type	Oie	Oa	Depth strata (cm)			Mineral soil total
				0-10	10-20	20+	
		mg Pb kg^{-1}					
840	Spodosol	25	46	13	7.8	5.3	
1000	Spodosol	57	37	19	16	13	
1000	Cryofolist	89	39				11.0
1200	Cryofolist	64	42				7.7

Table 8.--Concentration of extractable zinc by elevation, soil type and horizon or mineral soil depth strata

Elevation (m)	Soil type	Oie	Oa	Depth strata (cm)			Mineral soil total
				0-10	10-20	20+	
		mg Zn kg^{-1}					
840	Spodosol	145	78	21	18	15	
1000	Spodosol	99	41	14	14	9.8	
1000	Cryofolist	533	84				7.0
1200	Cryofolist	188	98				24

Base saturation decreased greatly with increasing elevation in the mineral soil of spodosols from 14-21% at 840 m to 7-8% at 1000 m (Table 10). No further decrease in base saturation is evident in the mineral soil present in cryofolists at high elevation. The higher base saturation in the forest floor of cryofolist soils than in spodosols at 1000 m elevation was unexpected.

Soil pH decreased with increasing elevation in the forest floor, from 3.7 - 3.0 (Table 11). The pH increased with increasing soil depth in spodosols. The pH in the total mineral soil of the cryofolist soils was equivalent to that in the top 10 cm of the spodosols.

Table 9.--Concentrations of exchangeable cations by elevation and soil horizon for spodosols

Cation	Bh	Bs1	Bs2	C
	cmole + kg^{-1}			
		840 m Elevation		
K	0.19	0.08	0.051	0.09
Ca	1.0	0.31	0.13	0.44
Mg	0.43	0.29	0.052	0.13
Al	9.8	4.5	2.2	2.7
		1000 m Elevation		
K	0.35	0.17	0.078	0.083
Ca	0.30	0.20	0.15	0.13
Mg	0.25	0.11	0.065	0.036
Al	13.0	6.3	12.0	4.2

Table 10.--Base saturation by elevation, soil type and horizon or mineral soil depth strata

Elevation (m)	Soil type	Oie	Oa	Depth strata (cm) 0-10	10-20	20+	Mineral soil total
		Percent					
840	Spodosol	99	53	14	21	18	
1000	Spodosol	54	21.5	7.7	7.3	6.8	
1000	Cryofolist	80	43				7.7
1200	Cryofolist	74	42				7.1

Table 11.--Soil pH (0.01 M CaC1) by elevation, soil type and horizon or mineral soil depth strata

Elevation (m)	Soil type	Oie	Oa	Depth strata (cm) 0-10	10-20	20+	Mineral soil total
840	Spodosol	3.7	3.2	3.7	4.1	4.3	
1000	Spodosol	3.3	3.5	3.8	4.0	4.2	
1000	Cryofolist	3.1	3.0				3.7
1200	Cryofolist	3.1	3.0				3.8

Concentrations of available P increased with elevation for spodosols. This increase was unexpected based on the trend of increasing exchangeable Al over this elevation. The fact that organic matter concentration was much higher in higher elevation spodosols (Table 13) indicates a labile pool of organically bound P. There was a small decrease in available P with increasing elevation for cryofolists and between the spodosols at 840 m and the cryofolists at 1200 m (Table 12).

The concentration of organic matter in the forest floor was similar between soils and within soil types over the elevation range studied (Table 13). The spodosols at 1000 m had twice as much organic matter at all depths in the mineral soil as did spodosols at 840 m. The increase in organic matter may account for the higher concentration of exchangeable aluminum because of the importance of the organically bound Al pool.

Table 12.--Concentration of extractable phosphorous by elevation, soil type and horizon or mineral soil depth strata

Elevation (m)	Soil type	Oie	Oa	Depth strata (cm) 0-10	10-20	20+	Mineral soil total
		mg P kg^{-1}					
840	Spodosol	78	34	12	17	14	
1000	Spodosol	51	49	59	52	33	
1000	Cryofolist	56	37				17
1200	Cryofolist	49	26				15

Table 13.--Concentration of organic matter (loss on ignition) by elevation, soil type and horizon or mineral soil depth strata

Elevation (m)	Soil type	Oie	Oa	Depth strata (cm) 0-10	10-20	20+	Mineral soil total
		Percent					
840	Spodosol	92	59	15	10	4.8	
1000	Spodosol	80	63	29	21	12	
1000	Cryofolist	89	64				18
1200	Cryofolist	91	57				19

Element Pool Sizes

The quantitative determination of soil mass provides the basis for comparison of element pool sizes between soil types and elevations. Cryofolists contained only 15-20% as much mineral soil mass as did spodosols (Table 14). There was considerable variability in forest floor mass but, within cryofolists where the forest floor was by far the most important part of the rooting zone, Oa mass declined sharply with increasing elevation. Within spodosols there was a decrease in total exchangeable Ca with increasing elevation in the 0-10 cm strata and in the total mineral soil (Table 15). The Mg nutrient pool in the 0-10 cm strata decreased with increasing elevation, but there was no difference in the total mineral soil pools (Tables 15 & 16). Potassium pool sizes were equivalent in spodosols between 840 and 1000 m (Table 17). The pool sizes of Ca, K and Mg in the forest floor were much lower on cryofolists at 1200 m than for the other soil/elevation combinations.

Because of the much lower mineral soil mass in cryofolists the pool sizes of exchangeable Ca, Mg and K in the mineral soil were proportionately smaller (Tables 15, 16 & 17). In spodosols the forest floor accounted for about ½ of the total exchangeable pool of these nutrient elements whereas, it accounted for 75, 77 and 89% of K, Mg and Ca respectively in cryofolists.

The pool sizes of extractable P also indicated the importance of the forest floor in the cryofolists because of the relatively small nutrient reserve of this element in the mineral soil of cryofolists compared with spodosols (Table 18).

Table 14.--Oven dry soil mass by elevation, soil type and horizon or mineral soil depth strata

Elevation (m)	Soil type	Oie	Oa	Depth strata (cm)			Mineral soil total
				0-10	10-20	20+	
					Mg ha^{-1}		
840	Spodosol	19.5	88	283	273	859	1415
1000	Spodosol	67.1	119	230	306	1000	1540
1000	Cryofolist	29.8	131				228
1200	Cryofolist	30.0	70				338

Table 15.--Exchangeable calcium by elevation, soil type and horizon or mineral soil depth strata

Elevation (m)	Soil type	Oie	Oa	Depth strata (cm)			Mineral soil total
				0-10	10-20	20+	
					kg ha^{-1}		
840	Spodosol	66	91	31	23	25	89
1000	Spodosol	60	75	16	14	28	58
1000	Cryofolist	67	201				19
1200	Cryofolist	41	37				14

Table 16.--Exchangable magnesium by elevation, soil type and horizon or mineral soil depth strata

Elevation (m)	Soil type	Oie	Oa	Depth strata (cm)			Mineral soil total
				0-10	10-20	20+	
					kg ha^{-1}		
840	Spodosol	9.79	17	8.6	4.7	6.8	20
1000	Spodosol	7.7	8.1	5.9	5.6	9.5	21
1000	Cryofolist	6.0	22				3.7
1200	Cryofolist	4.8	6.5				6.2

Table 17.--Exchangeable potassium by elevation, soil type and horizon or mineral soil depth strata

Elevation (m)	Soil type	Oie	Oa	Depth strata (cm)			Mineral soil total
				0-10	10-20	20+	
					kg ha^{-1}		
840	Spodosol	16	30	17	9	24	50
1000	Spodosol	24	24	19	15	24	58
1000	Cryofolist	16	40				8.1
1200	Cryofolist	17	14				18

Table 18.--Extractable phosphorous by elevation, soil type and horizon or mineral soil depth strata

Elevation (m)	Soil type	Oie	Oa	Depth strata (cm) 0-10	10-20	20+	Mineral soil total
		kg ha^{-1}					
840	Spodosol	1.6	3.0	3.8	4.9	11	19.6
1000	Spodosol	3.2	5.6	11	17	32	61
1000	Cryofolist	1.6	4.6				4.6
1200	Cryofolist	1.4	1.5				4.8

Summary

In general, cryofolist soils had smaller nutrient pools than spodosol soils due to both lower soil mass and lower concentrations of exchangeable cations. For most elements, nutrient pools and concentrations of exchangeable cations decreased with increasing elevation in both soil types. Base saturation decreased and exchangeable Al increased with increasing elevation in spodosols. Lower nutrient reserves and low base saturations suggest that cryofolist soils may be more susceptible to cation depletion and loss of fertility by mechanisms such as cation leaching in the long term.

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Description of Crown Symptoms on Red Spruce and Balsam Fir in the Northeastern United States: A Progress Report

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Abstract

A cooperative survey to define crown symptoms on deteriorating red spruce and balsam fir is underway in New York, Vermont, New Hampshire, Massachusetts, and West Virginia. The objectives of the survey are to determine the frequency, geographic variability, and progression of crown symptoms, and also to determine which symptoms are caused by historically important damage agents and differentiate them from those for which causal agents cannot readily be determined. The permanent plots are established and the first year data collected in 1986 is summarized here. Little overall discoloration in the crown was noted, however foliage loss due to branch mortality or dieback was prevalent. The other common crown symptoms were broken branches and bunching of lateral shoots following terminal branch dieback. Needle retention on foliated red spruce and balsam fir branches was good, averaging 7 to 8 years. Subtle chlorotic mottling was common on sample branches cut from red spruce. Several biotic damage agents (insects and diseases), as well as abiotic agents such as wind, ice, and snow, have been found in association with some of the symptoms.

Introduction

A cooperative survey of red spruce and balsam fir decline and mortality in New York, Vermont, and New Hampshire was conducted in 1984 (Weiss et al 1985). The results of the survey indicated that there were areas where red spruce and balsam fir mortality was occurring in excess of 30 percent. A survey was also conducted in West Virginia to determine the distribution of the red spruce and balsam fir mortality (Mielke et al 1986). Another survey, conducted in Massachusetts, identified areas of tree mortality including red spruce (MacConnell et al 1986).

Based on the results of these earlier surveys, a Symptomatology Project was designed to describe the crown symptoms which were occurring on red spruce and balsam fir at various locations. The specific objectives of the Symptomatology Project are to: determine the frequency and geographic variability of visual crown symptoms on deteriorating red spruce and balsam fir; determine the progression of symptoms within tree crowns and within the forest as severity of damage increases; and identify and describe symptoms caused by historically important damage agents and differentiate them from those for which causal agents cannot be readily determined.

Materials and Methods

A total of 80 permanent plots were established in New York (in the Adirondacks and Tug Hill region), Vermont (on the Green Mountain National Forest and the northern portion of the state), and New Hampshire (on the White Mountain National Forest) in 1985; in West Virginia (on the Monongahela National Forest) in 1986; and in the Berkshire region of Massachusetts in 1987 (Miller-Weeks 1985, Millers and Miller-Weeks 1986a, Millers and Miller-Weeks 1986b) (Figure 1). The plot locations were chosen at random from areas delineated during the previous surveys using aerial photo interpretation and sketch mapping (Weiss et al 1985, Mielke et al 1986, MacConnell et al 1986).

The plots are located in areas of spruce-fir slope type (more than 50 percent of the trees are red spruce or balsam fir). In most cases the plots in the heavy mortality areas (stratified as more than 30 percent standing dead) are paired with plots located in areas stratified as having lower mortaility in order to compare symptoms and incidence of damage agents.

The plot pairs are divided into high and low elevation. Overall the plots range in elevation from 1000 feet in Tug Hill to 3900 feet in New Hampshire. (The plots are not paired nor are they located at varying elevations in Tug Hill, West Virginia, or in Massachusetts due to the lack of differences in mortality or location of the spruce-fir type.)

Each plot consists of a cluster of four 1/10 acre (405 m2) fixed radius subplots, with a milacre plot nested within each subplot (Miller-Weeks 1985). On each subplot 5 dominant or codominant red spruce or balsam fir greater than 5 inches dbh were randomly selected - a total of 20 trees per plot. For each sample tree several methods of tree vigor rating are used including: needle retention; the West German Damage Class Rating System (Ciesla et al 1986): the American Foliage and Tree Vigor Rating System (Miller-Weeks 1985): and, when applicable, the Dwarf Mistletoe Rating System (Hawksworth 1977). Root or stem injuries are recorded when present. The milacre plots were established to assess the condition and describe symptoms present on red spruce and balsam fir seedlings.

Crown data for each sample tree includes: branch abundance; proportion of branches dead, broken, or contorted; proportion of branches with brooms, bunched or tufted foliage, or resinosis;

and proportion of branches with foliage missing or discolored. Sample branches from the upper and lower crown are collected to determine internode length, needle length, needle abundance, bud or needle damage, and needle discoloration (faded green, chlorotic, necrotic, mottled, or flecked). When identifiable the damage causal agent for any symptom observed is recorded. The identifiable damage causal agents include insects, disease, and physical or weather related factors.

Results

A summary of the 1986 first year data for New York (the Adirondacks and Tug Hill), Vermont, New Hampshire, and West Virginia is presented here. Most of the discussion will center on the data acquired for the red spruce sample trees, highlighting the most common symptoms observed, and mentioning the major findings on balsam fir trees.

Both the North American and West German Rating Systems were used to assess the crown vigor of the sample trees, including discoloration and defoliation. In the Adirondacks, New Hampshire, Vermont, and West Virginia, over 75 percent of the red spruce trees were rated in the lowest North American class for discoloration (1 to 10 percent) (Figure 2). Very little overall chlorosis or necrosis in the crowns was observed.

However, defoliation (foliage loss) was rated as moderate (11 to 50 percent) on about 65 percent of the red spruce trees in each region (Figure 3). About 10 percent of the trees in each area showed severe foliage loss (more than 50 percent of the crown affected). Figures 2 and 3 suggest that the reason for downgrading the tree vigor ratings was due to foliage loss not discoloration. There is only slight variation from region to region except for Tug Hill. The discoloration and defoliation patterns for balsam fir and red spruce were similar. The results of the West German Vigor Ratings for discoloration and defoliation for were very similar to the North American Ratings (Figure 4 and Figure 5).

The needle retention on foliated red spruce and balsam fir branches was good. Most of the red spruce branches were rated in the 7 to 9 year needle retention category (Figure 6). The highest needle retention, 15 years, was observed in Tug Hill.

The defoliation (foliage loss) observed in the red spruce crowns was mainly due to individual branch mortality or branch dieback (Figure 7). Individual branch mortality within the live crown was observed on over 75 percent of the red spruce in each survey area. Dieback of terminal shoots was evident on over 65 percent of the red spruce in each region. Broken branches within the live crown were also prevalent in the Adirondacks, New Hampshire, and Vermont. The breakage is likely due to tree crowns knocking into one another during high winds. Bunching of foliage, a result of epicormic branching usually following terminal dieback caused by wind and ice, was also prevalent in the Adirondacks, New Hampshire, and Vermont. Large brooms caused by Eastern Dwarf Mistletoe (*Arceuthobium pusslum* Peck) were only found on a few of the sample trees. The causes of the common branch symptoms, including the individual branch mortality and dieback, require further investigation. In West Virginia, much of it is

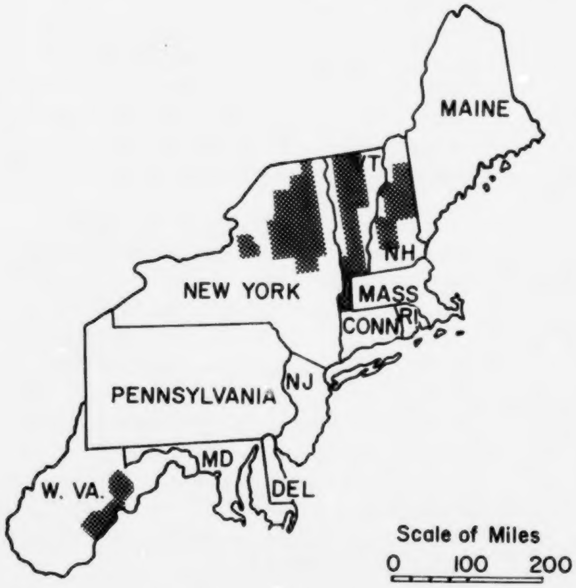

Figure 1.--Location of survey regions in New York, Vermont, New Hampshire, Massachusetts, and West Virginia where permanent plots for the red spruce and balsam fir symptomatology project were established.

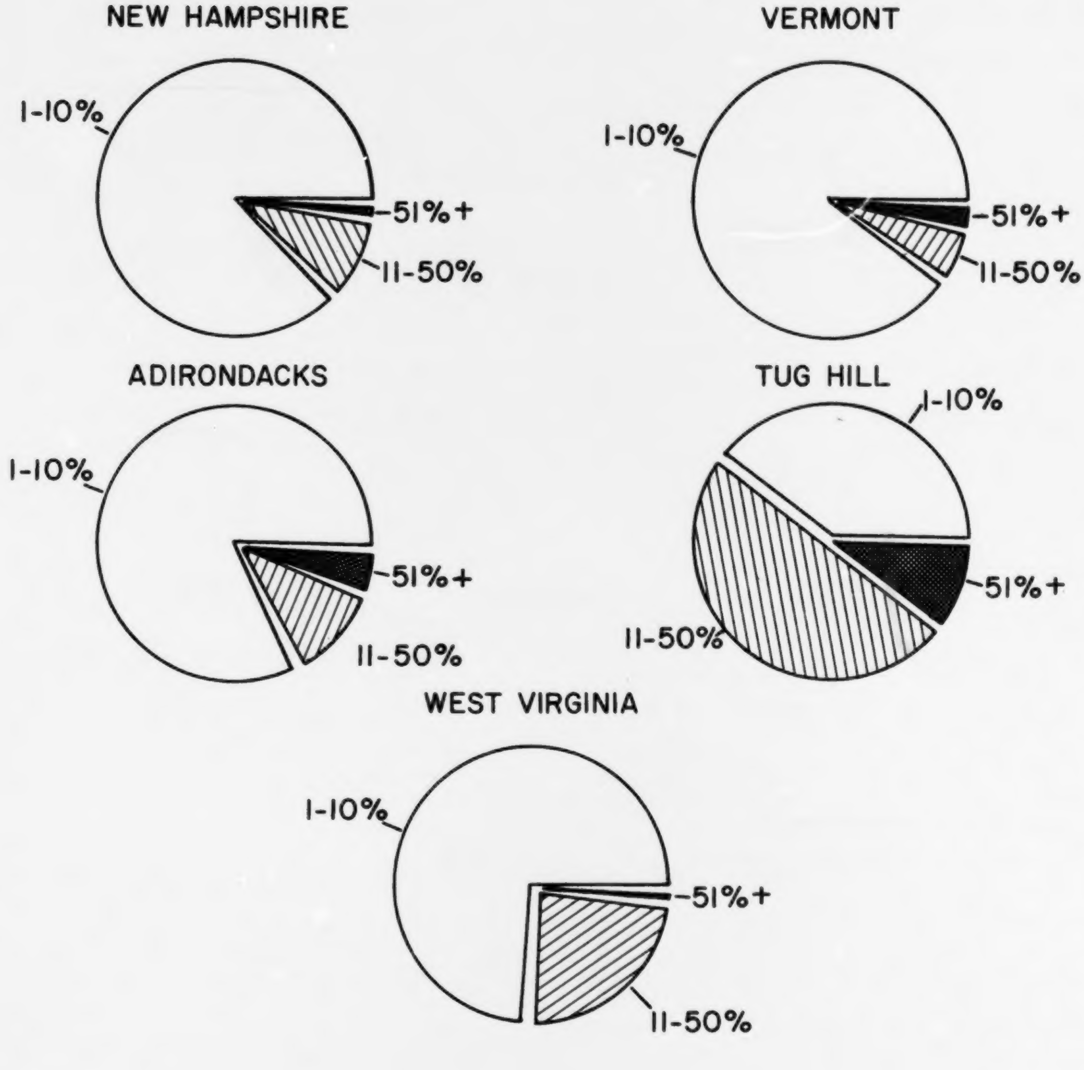

Figure 2.--Proportion of red spruce in the various North American Vigor Rating Classes for discoloration in New Hampshire, Vermont, the Adirondacks, Tug Hill, and West Virginia, 1986.

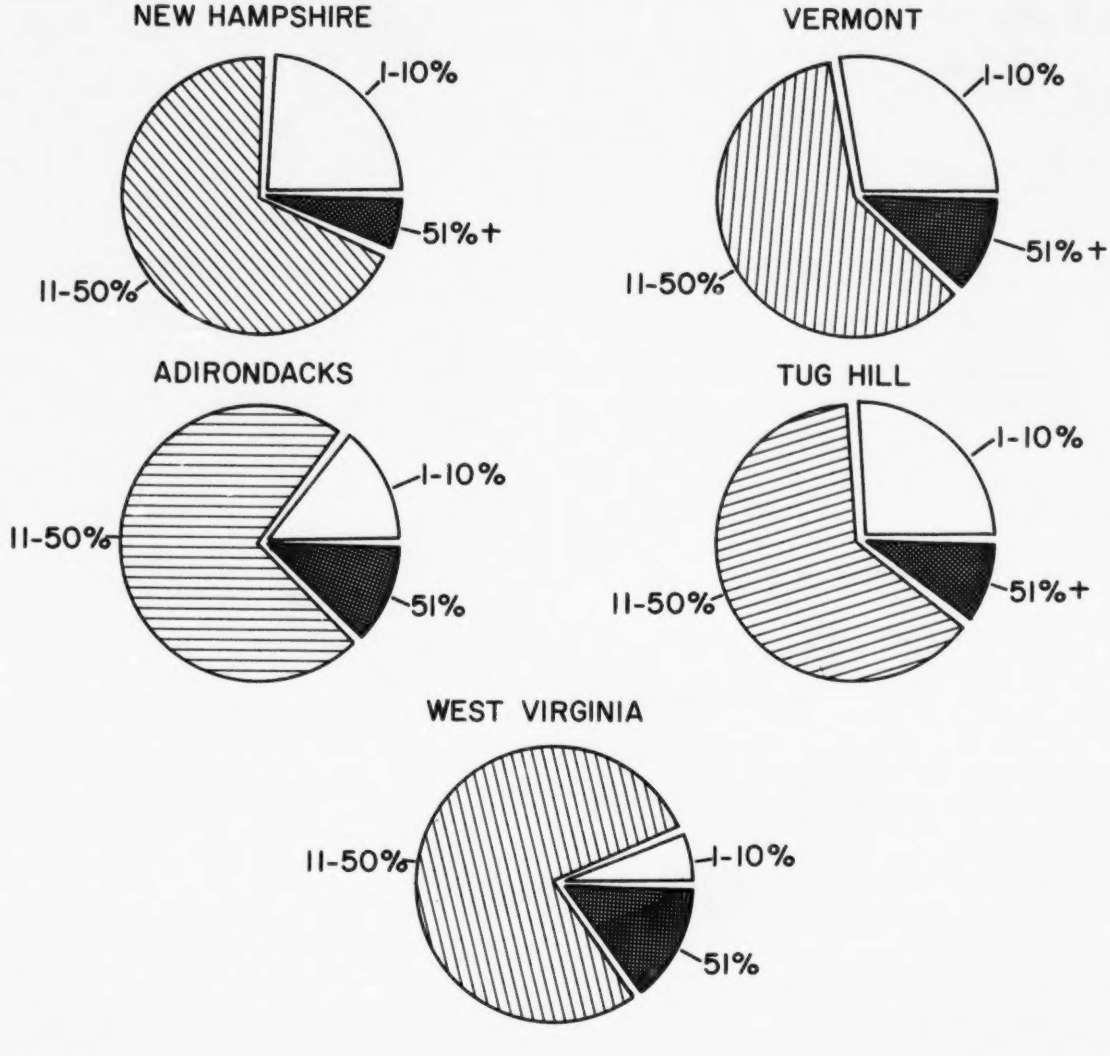

Figure 3.--Proportion of red spruce in the various North American Vigor Rating Classes for defoliation in New Hampshire, Vermont, the Adirondacks, Tug Hill, and West Virginia, 1986.

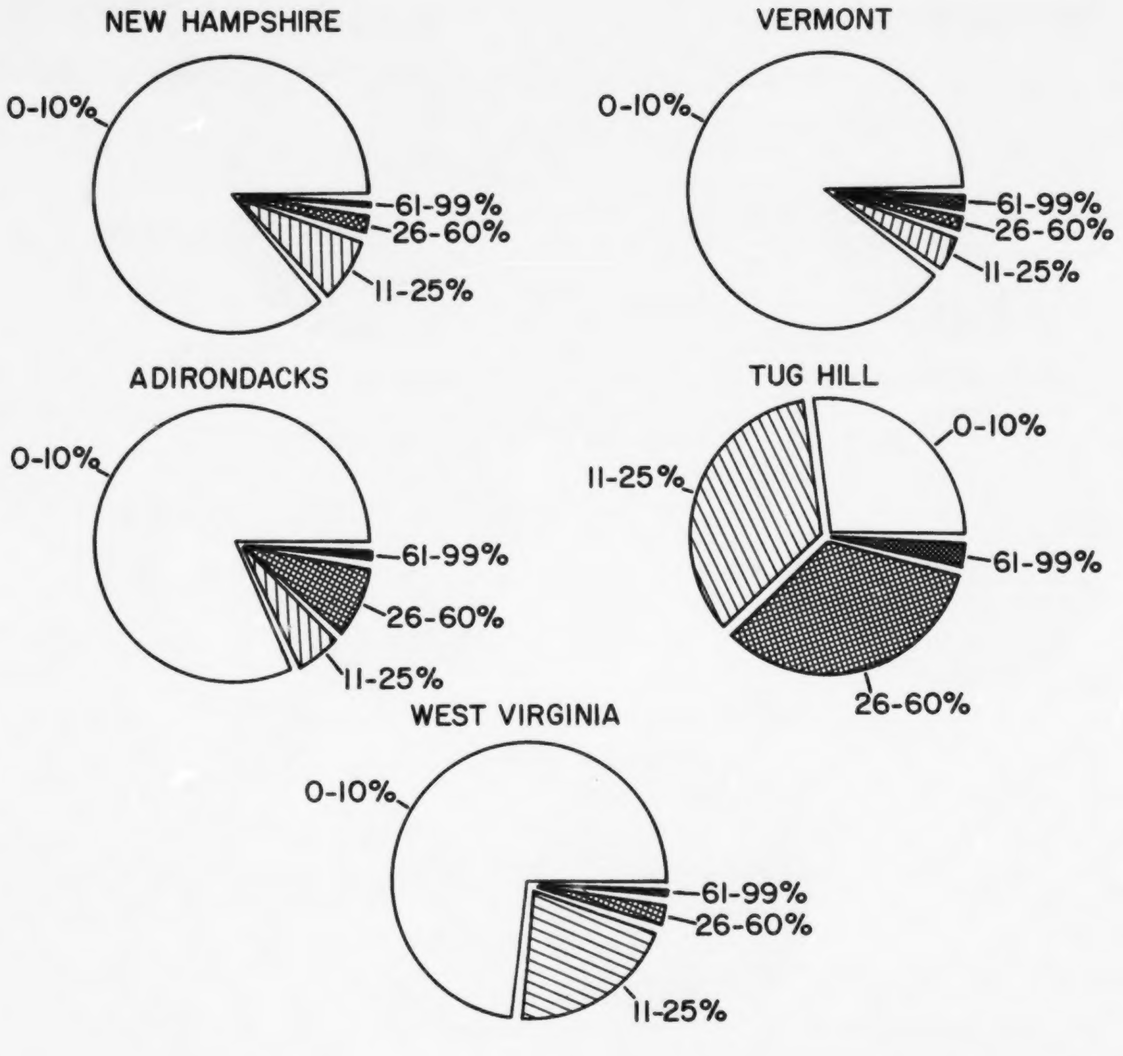

Figure 4.--Proportion of red spruce in the various West German Vigor Rating Classes for discoloration in New Hampshire, Vermont, the Adirondacks, Tug Hill, and West Virginia, 1986.

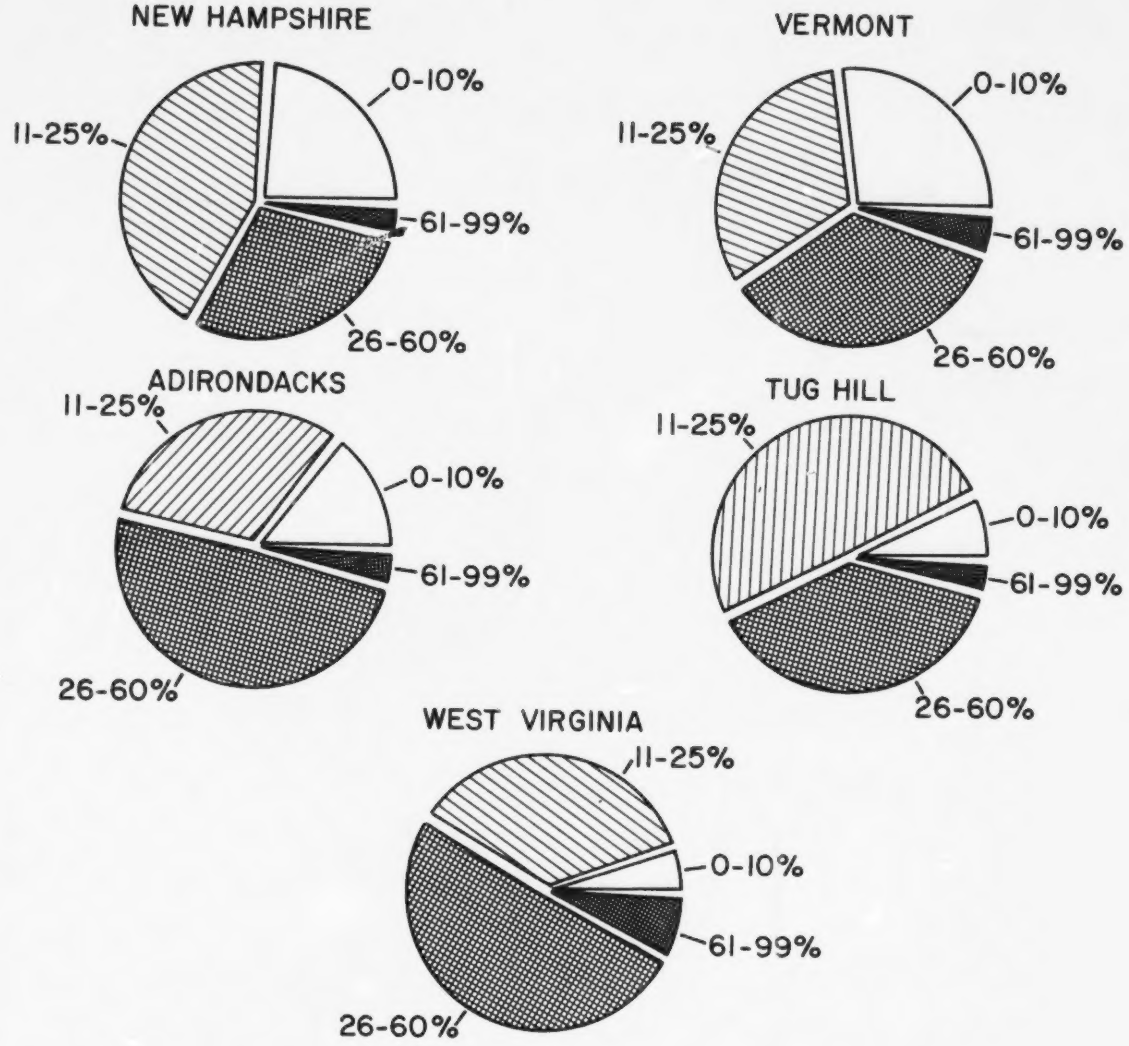

Figure 5.--Proportion of red spruce in the various West German Vigor Rating Classes for defoliation in New Hampshire, Vermont, the Adirondacks, Tug Hill, and West Virginia, 1986.

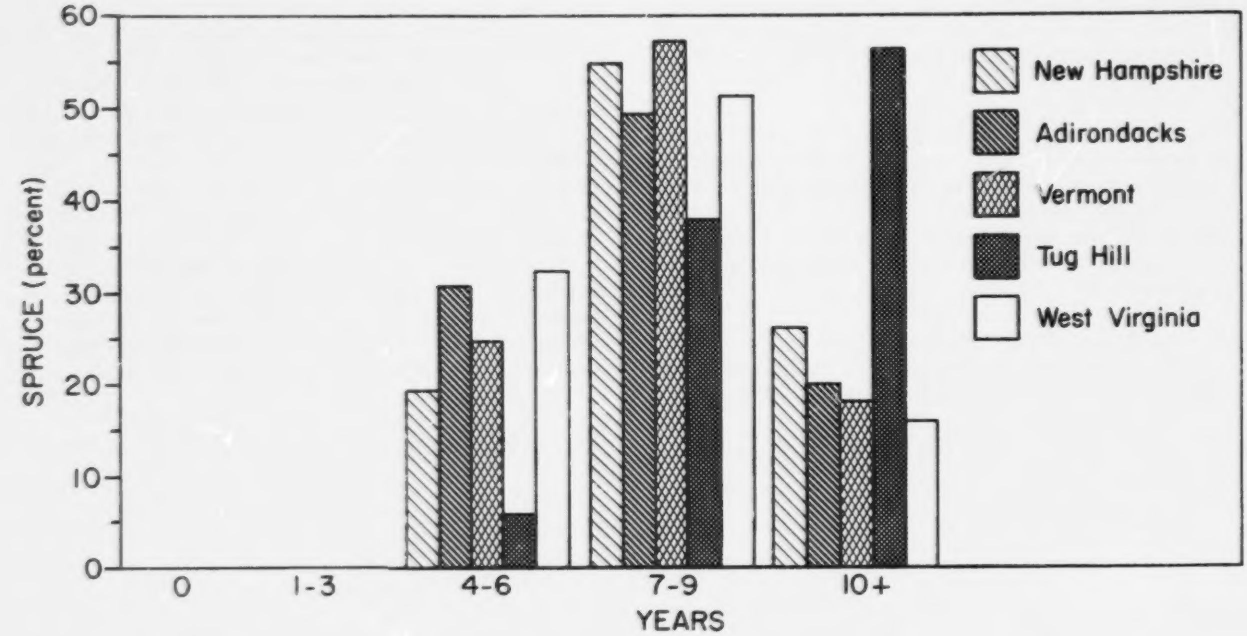

Figure 6.--Years of needle retention on live red spruce branches in the upper and lower crown of red spruce in the various survey regions, 1986.

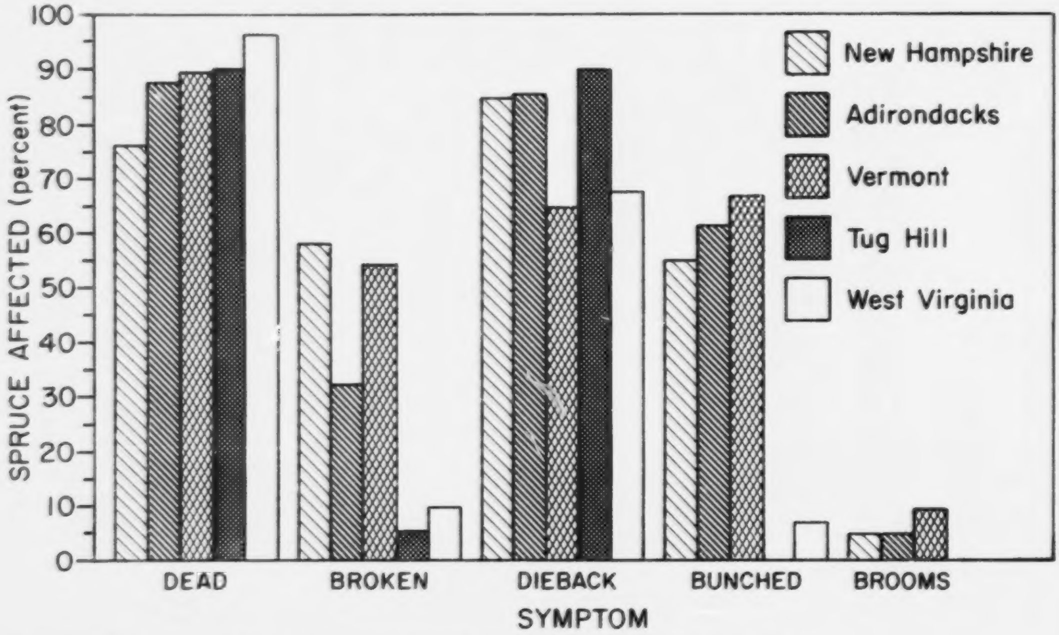

Figure 7.--Frequency of the most common branch symptoms in red spruce crowns in the various survey regions, 1986.

attributed to Cytospora Canker (*Valsa kunzei* Sacc.), but the incidence of the disease in the other survey regions has not been determined. The crown symptoms on balsam fir were similar to the red spruce except for bunching of foliage which occurred less frequently.

The branches collected from the upper and lower crowns of the red spruce were examined for growth characteristics and symptom expression. There was little variation of length from internode to internode or between survey areas. Also there was little variation between survey areas in needle length or number of needles per internode. Few needles were chewed, mined, twisted or galled.

To assess the various discoloration symptoms both sides of the branch were examined. The most common needle discoloration symptom found on red spruce is intermittent mottling (Table 1 and Table 2). This symptom is present in both the upper crown and lower crown, and on both the upper and lower side of the branches. Over 50 percent of the red spruce in New Hampshire, Vermont, and Tug Hill exhibited this symptom on the upper side of the branches in the upper crown, while fewer trees in the Adirondacks and West Virginia had this symptom (Figure 8). The next common symptom overall is chlorosis of the terminal half of the needle, in most cases the tip of the needle only. Other frequent symptoms observed on the cut branch included intermittent flecking and banding, whole needle faded green or chlorotic, and terminal half necrotic. The occurance of chloritic tips and mottling was not as prevalent in the fir as the spruce, but the fir had a slightly higher frequency of flecking. The frequency of each symptom varied between regions. The significance and causal agents of these various needle symptoms observed on the cut branches has yet to be determined.

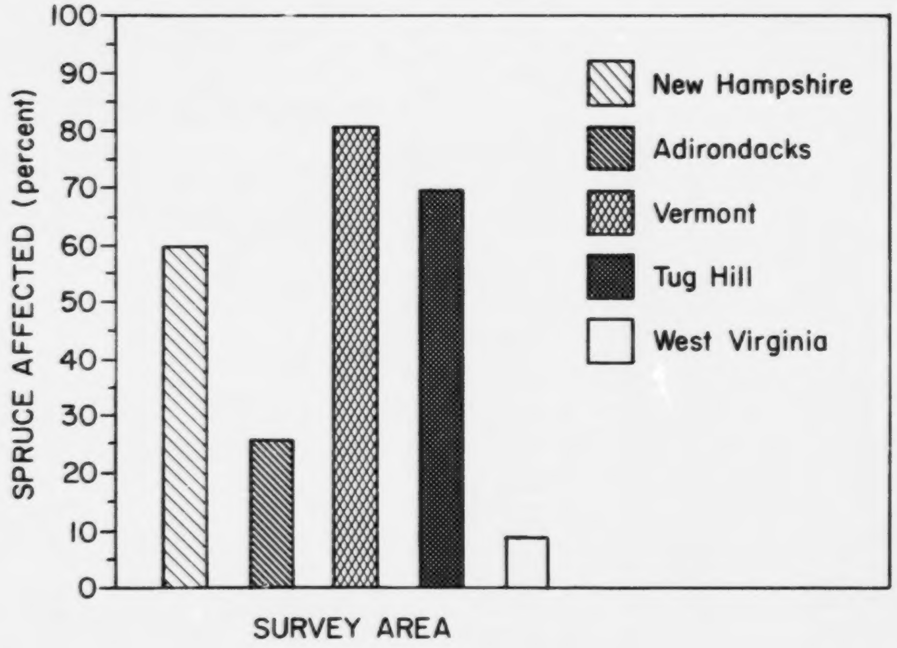

Figure 8.--Proportion of red spruce in the various survey regions with intermittent chlorotic mottling on the upper surface of the branch cut from the upper crown, 1986.

Table 1.--Proportion of red spruce with various symptoms of needle discoloration in the upper crown on the upper and lower side of branches in New York, Vermont, New Hampshire, and West Virginia (based on 50-cm cut branches)

Needle symptom	Tug Hill	New Hampshire	Adirondacks	Vermont	West Virginia
	----------	----------	Percent	----------	----------
			UPPER SIDE OF BRANCH		
Whole needle					
Faded green	38.8	11.7	5.6	21.6	19.5
Chlorotic	28.2	36.4	10.7	50.8	13.7
Necrotic	2.9	30.9	4.4	13.5	3.4
Terminal half					
Faded green	1.0	1.9	3.2	3.2	10.2
Chlorotic	26.2	18.5	20.6	48.1	17.6
Necrotic	22.3	13.6	13.1	43.8	4.9
Basal half					
Faded green	1.0	0	0.8	0.5	9.3
Chlorotic	0	1.2	1.6	2.2	3.9
Necrotic	4.9	0.6	0.8	3.2	2.9
Intermittent					
Mottled	69.9	59.9	25.8	82.2	8.8
Flecked	9.7	38.3	16.7	57.3	5.9
Banded	26.2	9.9	8.3	12.4	4.4
			LOWER SIDE OF BRANCH		
Whole needle					
Faded green	10.7	6.8	3.6	4.9	14.1
Chlorotic	19.4	25.3	4.0	19.5	6.3
Necrotic	3.9	24.7	2.0	11.4	2.9
Terminal half					
Faded green	6.8	1.2	0.4	0.5	8.3
Chlorotic	6.8	1.2	0.8	7.6	9.3
Necrotic	1.0	2.5	1.6	7.6	3.9
Basal half					
Faded green	1.9	0	0.8	0.5	4.9
Chlorotic	0	0.6	1.2	1.6	2.0
Necrotic	3.9	0.6	1.6	1.1	2.0
Intermittent					
Mottled	53.4	40.7	10.3	45.9	7.8
Flecked	7.8	35.8	13.1	44.3	5.4
Banded	26.2	10.5	6.0	15.1	3.9

Table 2.--Proportion of red spruce with various symptoms of needle discoloration in the lower crown on the upper and lower side of branches in New York, Vermont, New Hampshire, and West Virginia (based on 50-cm cut branches)

Needle symptom	Tug Hill	New Hampshire	Adirondacks	Vermont	West Virginia
	Percent				
			UPPER SIDE OF BRANCH		
Whole Needle					
Faded green	14.6	12.3	17.1	22.2	30.8
Chlorotic	22.3	29.0	16.7	35.1	16.7
Necrotic	2.9	25.3	5.6	14.1	6.6
Terminal half					
Faded green	0	4.9	6.7	5.4	15.2
Chlorotic	16.5	16.7	28.6	36.8	26.3
Necrotic	14.6	11.7	11.9	21.1	4.5
Basal half					
Faded green	1.0	0.6	0.8	1.1	11.6
Chlorotic	3.9	1.9	0.4	2.2	4.0
Necrotic	2.9	1.2	1.2	4.3	3.0
Intermittent					
Mottled	59.2	61.7	40.1	86.5	10.6
Flecked	1.9	38.3	17.5	53.5	12.6
Banded	25.2	16.7	9.5	28.6	8.1
			LOWER SIDE OF BRANCH		
Whole needle					
Faded green	6.8	8.0	7.9	8.6	19.7
Chlorotic	11.7	20.4	6.0	11.4	8.1
Necrotic	1.0	19.1	0.8	8.1	3.5
Terminal half					
Faded green	1.0	1.2	1.2	0	10.6
Chlorotic	15.5	3.1	4.4	5.9	11.6
Necrotic	8.7	2.5	2.4	3.8	1.5
Basal half					
Faded green	0	1.2	0.8	1.1	3.5
Chlorotic	1.9	1.2	11.2	1.6	2.0
Necrotic	2.9	3.1	2.4	3.2	1.0
Intermittent					
Mottled	47.6	38.9	11.1	32.4	5.1
Flecked	4.9	30.2	12.7	35.7	9.1
Banded	17.5	16.0	7.9	25.4	6.1

The most common trunk symptom found on the red spruce was resinosis (Figure 9). Resinosis is a typical symptom of *Fomes pini* Thore, and several isolations were made which confirmed the presence of the organism. Other common trunk symptoms were long stem cracks, swellings, and mechanical wounds. A few of the red spruce sample trees in the Adirondacks were infested with the spruce beetle (*Dendroctonus rufipennis* Kirby). The most common trunk symptom of balsam fir was cracks between the root buttresses, an indication of root and butt rot. Less than 5 percent of the trees had dead tops.

Over 70 percent of the red spruce seedlings in the Adirondacks, New Hampshire, and West Virginia were healthy, exhibiting no signs of discoloration or defoliation (Figure 10). The highest incidence of light discoloration was found in Vermont and Tug Hill. In Vermont, only 10 percent of the seedlings within the milacre plots were found to have more than 50 percent of the foliage discolored. Some of the discoloration was attributed to needlecast diseases. There were no red spruce seedlings in the other regions with more than 50 percet of the foliage discolored. Some of the discoloration noted on balsam fir seedlings was attributed to a rust disease.

This summary of the first year data collected in 1986 illustrates the most common symptoms occuring on red spruce and balsam fir within the survey regions. The sites are visited annually to determine the changes in symptom expression and frequency that may occur from year to year. The 1987 data are being analyzed and a progress report will be available early in 1988.

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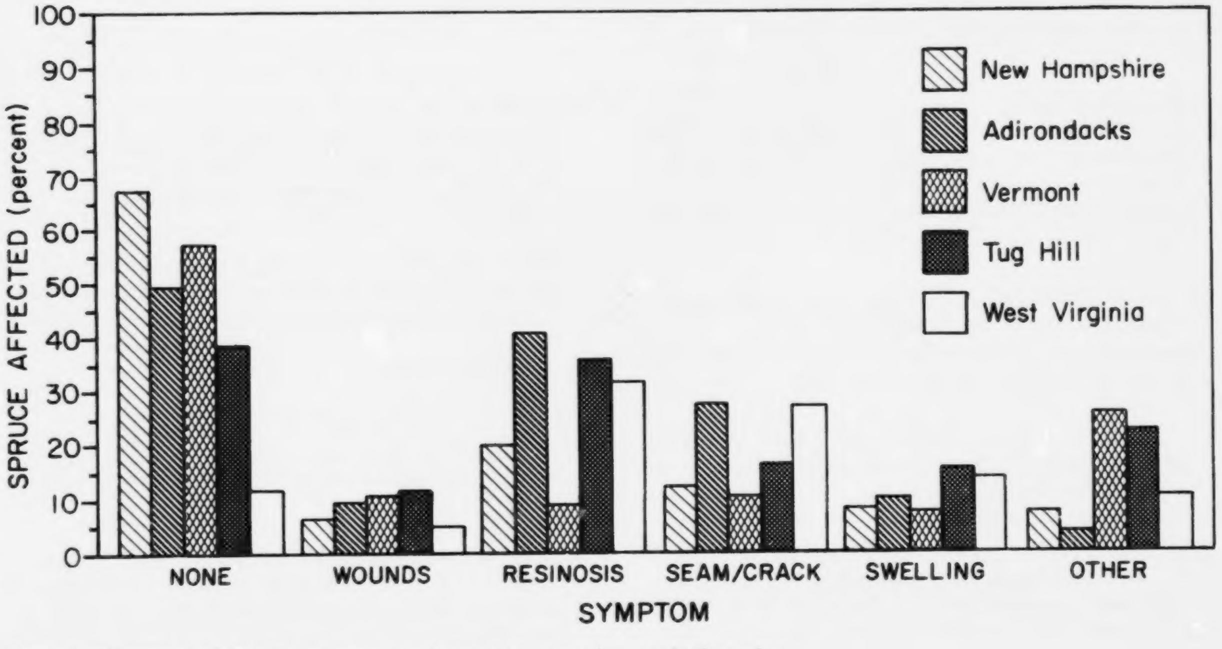

Figure 9.--Frequency of the most common trunk symptoms on red spruce in the various survey regions, 1986.

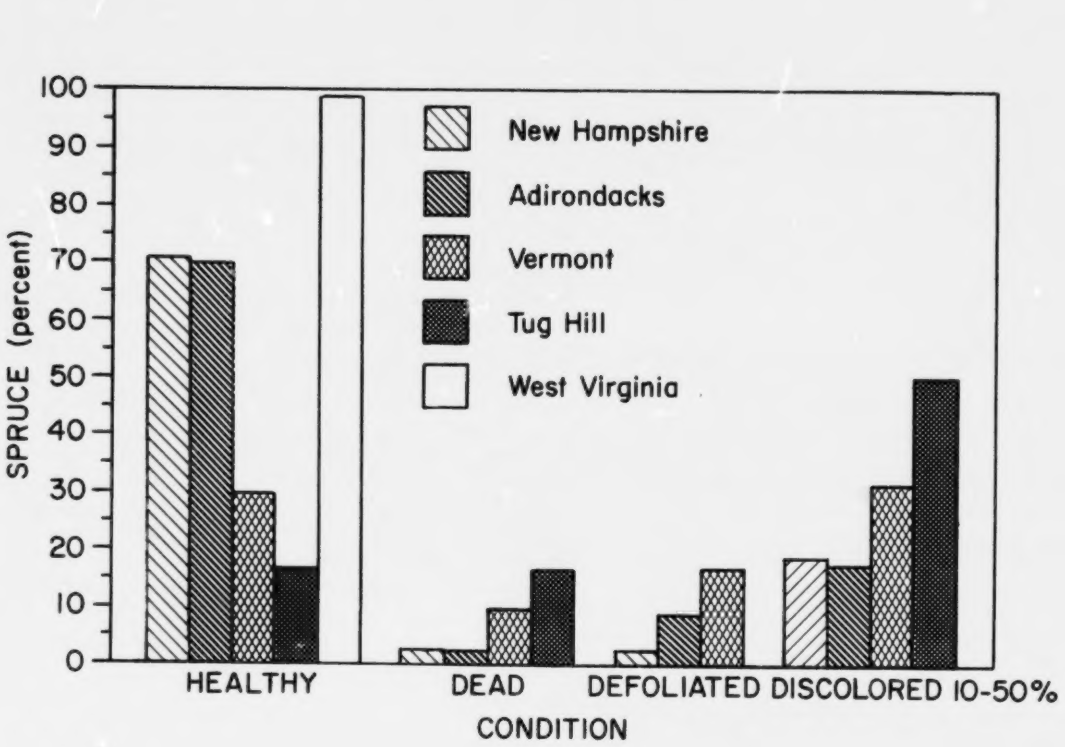

Figure 10.--Proportion of healthy, dead, defoliated, or discolored red spruce seedlings in the various survey regions, 1986.

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Red Spruce and Balsam Fir Mortality Mapping in New York, Vermont, New Hampshire and Western Maine: A Progress Report

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Abstract

Areas of red spruce and balsam fir in portions of New York, Vermont, New Hampshire, and western Maine are being mapped from color infrared aerial photographs acquired in 1985 and 1986. The spruce-fir stands are stratified by cover type and mortality class. Mortality classes are determined by the proportion of standing dead trees in a particular area. The Maine Geographic Information System is being used to determine the acreage in each spruce-fir cover type by mortality class and elevational zone. Maps will show the location of the various spruce-fir types and mortality classes in each state. Preliminary results from Vermont and the White Mountain National Forest are presented.

Introduction

In response to public and landowners concerns about the health of the spruce-fir forest in the northeastern United States, a Cooperative Survey of Red Spruce and Balsam Fir Decline and Mortality in New York, Vermont, and New Hampshire was conducted in 1984 (Weiss et al 1985). Survey blocks were randomly selected and aerially photographed. The results of this survey indicated that there was a significant amount of mortality of red spruce and balsam fir occurring in some areas.

As an extention of the original survey, an aerial photography project was initiated in New York, Vermont, New Hampshire, and western Maine (Figure 1). About 4.5 million acres were photographed. The objective of this project is to map and determine the acreages of the red spruce and balsam fir mortality within the designated survey areas by spruce-fir cover type, mortality class, and elevational zone. The mapping and analysis of acres affected will provide baseline data against which future forest conditions can be compared. Our plans are to photograph the same areas again in 1989 or 1990 to determine if any major changes have occurred in the condition of the forest.

Materials and Methods

Aerial Photography

The survey areas were aerially photographed in 1985 and 1986 with Kodak Aerochrome Color Infrared film using a Zeiss RMK 21/23 9-inch format camera with an 8-¼-inch focal length lens. The majority of the photography was acquired in 1985 at a scale of 1:24,000 and additional areas were flown in 1986 at a scale of 1:20,000. The USDA Forest Service Methods Application Group in Fort Collins, Colorado acquired most of the aerial photography and a small portion of the photo mission was accomplished by the USDA Forest Service Pest Management Staff in Atlanta, Georgia.

Complete stereo photo coverage of the White Mountain National Forest in New Hampshire and the Green Mountain National Forest in Vermont was obtained. Through the use of aerial sketch mapping, areas were also selected to be photographed in northern Vermont, in the Adirondacks, and western Maine. The selection of these areas was based on the percent of spruce-fir type and amount of mortality present. Areas previously affected by spruce budworm defoliation in New York, Vermont, and New Hamshire were eliminated from the survey area.

Photo Interpretation and Map Transfer

The 9x9 inch color infrared film positives (transparencies) are being interpreted according to established guidelines (Ciesla 1984). The photos are laminated and indexed, then the effective area of each photo is delineated. Bausch and Lomb SIS-95 Zoom Stereoscopes are being used for the photo interpretation.

The photos are being interpreted based on the following cover types and mortality classes:

Spruce-fir cover types:

Spruce-fir bog - greater than 50% spruce and fir in bogs
Spruce-fir slope - greater than 50% spruce and fir
Mixedwood - 25 to 50% spruce and fir
Balsam fir - greater than 90% fir

(Areas with predominently hardwoods, other conifers, krumholtz, rock outcrops, water, and residential areas are catagorized as other type)

Mortality classes - Within each spruce-fir cover type the status of mortality is classified as:

Light - less than 10% standing dead
Moderate - 10 to 30% standing dead
Heavy - greater than 30% standing dead

The photo interpreters stratify cover types and assign mortality classes. The minimum polygon size delineated is 20 acres. After the photo interpretation is complete then the polygons are transferred from the photos, using a Bausch and Lomb Stereo Zoom Transfer Scope, to 7-½ minute USGS Topographic Maps (or to 15 minute maps if coverage is not available). Each photo interpreter receives intensive technical training in photo interpretation techniques through lab practice and ground truth verification. Interpreters are checked continuously for correct species and mortality class identification and proper transfer techniques.

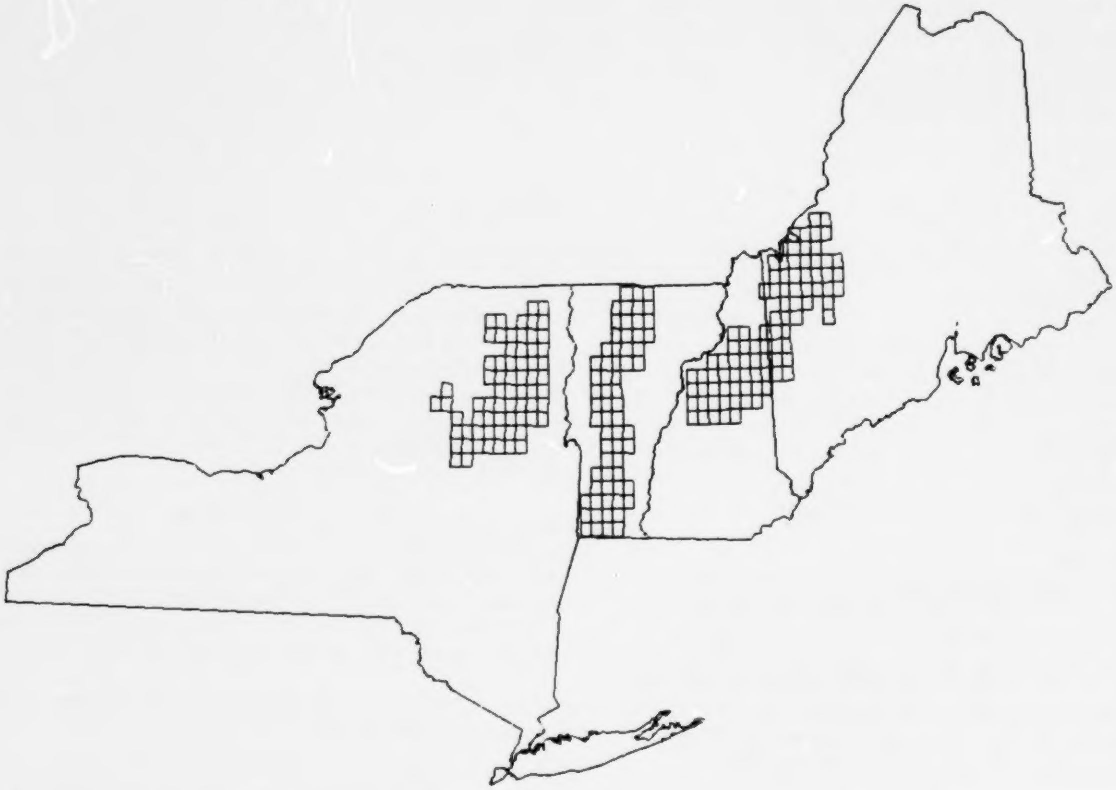

Figure 1.--Survey area for the red spruce and balsam fir mortality mapping project in New York, Vermont, New Hampshire, and Western Maine.

Geographic Information System and Mapping

The Maine Geographic Information System at the University of Maine in Orono is being used to process and store the data. For each area, the cover types and mortality classes delineated on the USGS Topographic Maps are digitized and labeled as one geographic layer. The elevational data from the appropriate USGS Topographic Map is also digitized as a separate geographic layer. All digitized data is checked for proper location and labeling.

An overlay is made of the two geographic layers to produce the acreage tables showing cover type (spruce-fir bog, spruce-fir slope, mixedwood, and balsam fir) and mortality class (low, moderate, or heavy) by elevational zone. The elevational zones are: less than 2600 feet, 2600 to 3600 feet, 3600 to 4600 feet, and greater than 4600 feet.

Maps are being produced showing the location of the various spruce-fir cover types and mortality classes. For each state a cover type map and a mortality map will be produced. The cover type map will show the location of all the spruce-fir cover types and the mortality map will show the location of all of the areas with moderate or heavy mortality. A USGS Topographic Map index grid will overlay these maps to show what map covers a particular area. This will allow users interested in a particular area to request the information and have the cover type and mortality information plotted directly onto the specific topographic map.

Preliminary Results

The data for Vermont and the White Mountain National Forest in New Hampshire have been processed. The acreages in the various cover types and mortality classes by elevation in the two States are presented here. Maps showing the location of the spruce-fir cover type (Figs 2, 4) and areas of moderate or heavy mortality (Figs. 3, 5) are also presented here as an example of the mapping information that will be available in the final report which will be published when the data for all the States has been processed.

The spruce-fir cover types (including spruce-fir swamp, mixedwood, spruce-fir slope, and balsam fir) comprise 14 percent (183,256 acres) of the total White Mountain National Forest survey area (Figure 2) and 4 percent (51,696 acres) of the total Vermont survey area (Figure 4). The spruce-fir cover types comprise only 7 percent of the total survey area at elevations less than 2600 feet on the White Mountain National Forest and 2 percent in Vermont. The rest of the forested area is made up of hardwoods, hemlock, and white pine. The spruce-fir cover types comprise about 83 percent of the total survey area from 3600 to 4600 feet in each state. On the White Mountain National Forest 80 percent of the total survey area above 4600 feet is krumholtz or bare rock. There were no spruce-fir cover types above 4600 feet in Vermont.

On the White Mountain National Forest, 65 percent of the spruce-fir cover types were stratified as spruce-fir slope, 29 percent as mixedwood, 4 percent as balsam fir, and 1 percent as spruce-fir swamp. In the Vermont survey area there was more mixedwood type (56 percent of all spruce-fir cover types) and less spruce-fir slope type (39 percent of all spruce-fir cover types) than on the White Mountain National Forest. Only 2 percent of the total spruce-fir cover type in Vermont was spruce-fir swamp and 3 percent was balsam fir.

Most of the spruce-fir cover types are located at less than 3600 feet on the White Mountain National Forest and in Vermont. Only 17 percent (30,777 acres) of the spruce-fir cover types are located above 3600 feet in the White Mountain National Forest and only 5 percent (2,574 acres) in Vermont.

On the White Mountain National Forest 44 percent of the spruce-fir cover types were stratified as having light mortality, 30 percent with moderate mortality, and 26 percent with heavy mortality. Figure 3 shows the areas of moderate and heavy mortality on the White Mountain National Forest. Over 42 percent (19,992 acres) of the heavy mortality occurs in the spruce-fir slope type at 2600

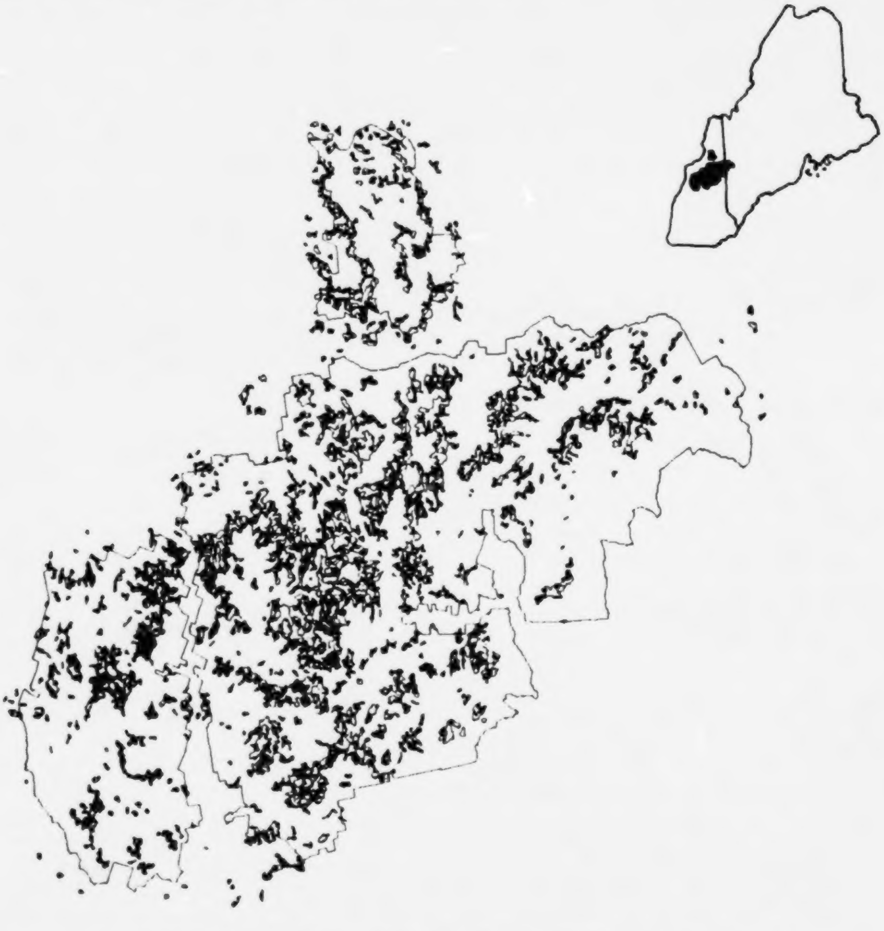

Figure 2.--Location of all spruce-fir cover types (including spruce-fir swamp, mixedwood, spruce-fir slope, and balsam fir) on the White Mountain National Forest.

to 3600 feet (Table 1). About 32 percent (29,607 acres) of the light mortality occurs in the spruce-fir slope type at elevations less than 2600 feet. Overall, 53 percent of the heavy mortality occurs at 2600 to 3600 feet, while 30 percent occurs at 3600 to 4600 feet.

Almost all of the spruce-fir swamp type on the White Mountain National Forest is located at elevations less than 2600 feet and has light mortality. Most of the balsam fir type is located at 3600 to 4600 feet has moderate or heavy mortality.

In Vermont 61 percent of the spruce-fir cover types were stratified as have light mortality, 26 percent with moderate mortality, and 13 percent with heavy mortality. Figure 5 shows the location of areas with moderate and heavy mortality in Vermont. Over 43 percent (2,824 acres) of the heavy mortality occurs in the mixedwood type at 2600 to 3600 feet (Table 2). About 41 percent (13,021 acres) of the light mortality occurs in the mixedwood type at elevations less than 2600 feet. Overall, 74 percent of the heavy mortality occurs at 2600 to 3600 feet.

As on the White Mountain National Forest, most of the spruce-fir swamp type in Vermont is at elevations less than 2600 feet has light mortality. Most of the balsam fir type is located at 2600 to 3600 feet, and as on the White Mountain National Forest has moderate or heavy mortality.

The Vermont and the White Mountain National Forest data were presented here as an example of the type of information on the location of red spruce and balsam fir mortality that will be available when all the data has been processed. The complete report, including a complete discussion of the relative locations of the mortality in each survey will be available in 1988.

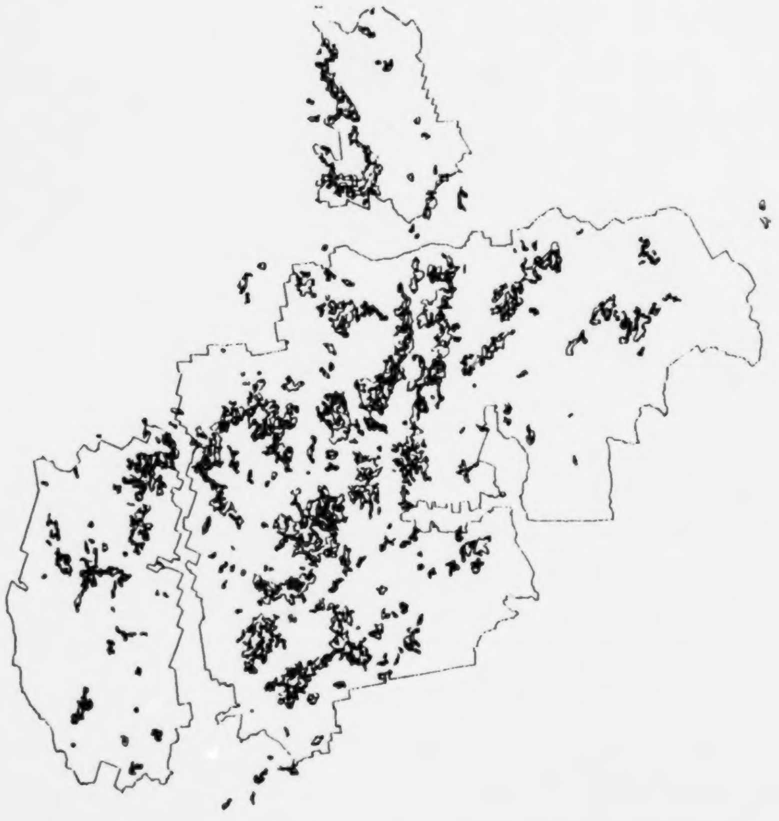

Figure 3.--Location of all spruce-fir cover types with moderate and heavy mortality on the White Mountain National Forest.

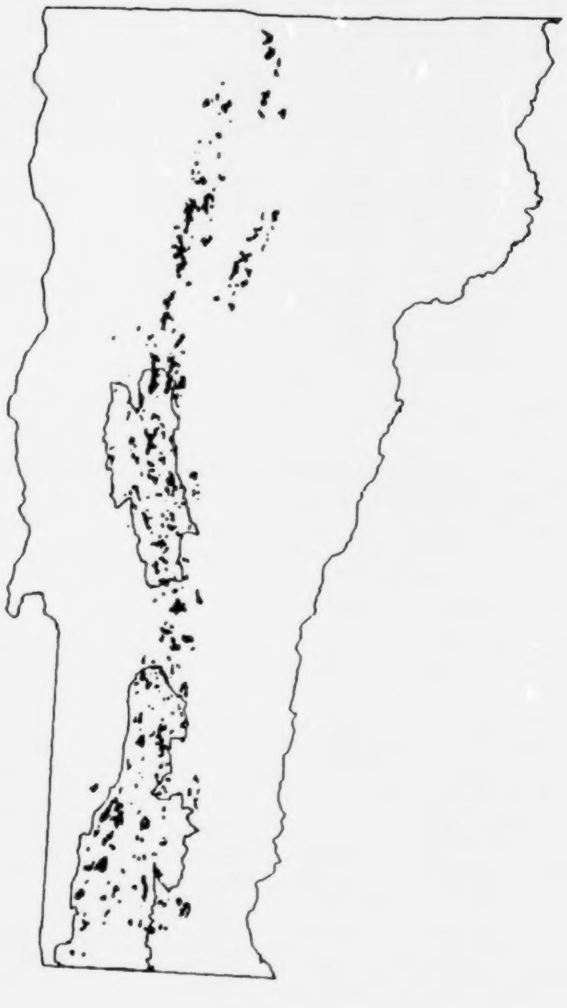

Figure 4.--Location of all spruce-fir cover types (including spruce-fir swamp, mixedwood, spruce-fir slope, and balsam fir) in Vermont. (Northeastern Vermont was excluded from this survey due to previous spruce budworm defoliation in that area.)

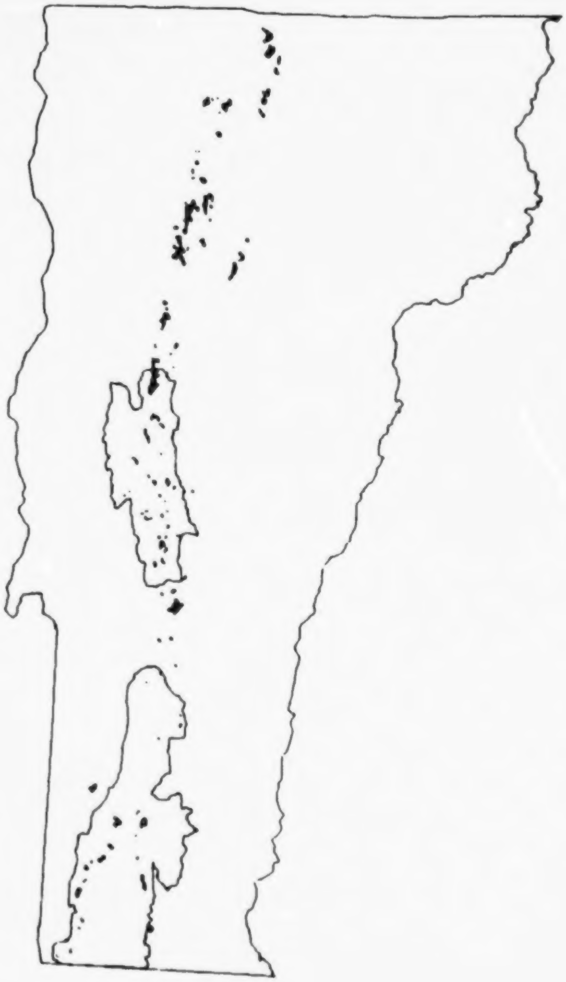

Figure 5.--Location of all spruce-fir cover types with moderate and heavy mortality in Vermont. (Northeastern Vermont was excluded from this survey due to previous spruce budworm defoliation in that area.)

Table 1.--Area of each spruce-fir cover type and mortality class by elevational zone on the White Mountain National Forest in New Hampshire, 1985 (based on aerial photo interpretation and GIS analysis)

	Elevational zone				
Cover type and mortality class	2600 ft.	2600-3600 ft.	3600-4600 ft.	4600 ft.	Total
	acres				
Spruce fir swamp					
Light mortality	754	51	0	0	806
Moderate mortality	455	0	0	0	455
Heavy mortality	73	18	0	0	91
Mixedwood					
Light mortality	18,802	9,574	699	0	29,075
Moderate mortality	5,700	10,282	1,238	0	17,220
Heavy mortality	2,329	4,609	658	0	7,596
Spruce-fir slope					
Light mortality	29,607	14,592	5,405	94	49,698
Moderate mortality	11,387	18,387	5,951	64	35,789
Heavy mortality	5,142	19,992	9,627	160	34,921
Balsam fir					
Light mortality	0	36	276	127	439
Moderate mortality	0	184	1,842	570	2,596
Heavy mortality	0	505	3,789	276	4,570
Total					183,255

Table 2.--Area of each spruce-fir cover type and mortality class by elevational zone in Vermont (including the Green Mountain National Forest), 1985 (based on aerial photo interpretation and GIS analysis)

	Elevational zone				
Cover type and mortality class	2600 ft	2600-3600 ft	3600-4600 ft	4600 ft	Total
	acres				
Spruce fir swamp					
Light mortality	685	191	0	0	876
Moderate mortality	149	154	0	0	303
Heavy mortality	31	0	0	0	31
Mixedwood					
Light mortality	13,022	5,067	306	0	18,395
Moderate mortality	2,056	4,400	208	0	6,664
Heavy mortality	594	2,824	236	0	3,654
Spruce-fir slope					
Light mortality	9,325	2,477	258	0	12,060
Moderate mortality	1,338	3,885	809	0	6,032
Heavy mortality	200	1,637	377	0	2,214
Balsam fir					
Light mortality	258	14	0	0	272
Moderate mortality	71	419	160	0	650
Heavy mortality	17	323	205	0	545
Total					51,696

Acknowledgments

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Condition of Red Spruce in West Virginia

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Abstract

The condition of red spruce in West Virginia was evaluated in 1985. Approximately 110,685 acres of forest land in the state has a red spruce component. About 1,603 acres has mortality exceeding 30 percent of standing red spruce. Dead and declining trees represent 33 percent of the total red spruce volume. Cytospora canker was associated with crown symptoms on 63 percent of declining trees.

Introduction

Surveys of red spruce (*Picea rubens* Sarg.) in West Virginia were begun in 1985. They were promted by the discovery of large numbers of dead and dying red spruce on the Monongahela National Forest in 1983 (Mielke et al. 1984), and reports of widespread decline and mortality of red spruce throughout its range (Johnson and Siccama 1983, Adams et al 1985, Hornbeck and Smith 1985, Weiss et al 1985).

Red spruce occurs in the east central part of West Virginia, physiographically characterized by parts of the unglaciated Allegheny Mountains. The bulk of the red spruce forest is on the Monongahela National Forest, and to a lesser extent, intermingled state and private ownerships (Figure 1). In addition, many plantations of red spruce and Norway spruce, *Picea abies* (L.) Karst., were established within the natural range of red spruce in West Virginia during the 1930's.

In the northern part of its range, red spruce is commonly associated with a mixture of northern hardwoods, eastern hemlock, *Tsuga canadensis* (L.) Carr., eastern white pine, *Pinus strobus* L., and balsam fir. The latter species is replaced by Fraser fir, *A. fraseri* (Pursh) Poir., in the southern Appalachians. In West Virginia, red spruce occurs in association with northern hardwoods at the lower elevations, eastern hemlock and hardwoods growing in drainages, and in nearly pure stands at elevations above about 3,800 feet. In West Virginia, balsam fir is restricted to four locations (Core 1966), and Fraser fir does not occur naturally. Except for the absence of fir, spruce stands in West Virginia are not compositionally distinct from comparable stands in the northeast or in the southern Appalachian Mountains (Stephenson and Clovis 1983).

Red spruce apparently was widely distributed in West Virginia during the last ice age. After the glaciers receded and the climate moderated, red spruce became restricted to the higher elevations. There were about 1.5 million acres of spruce forest when the first white settlers occupied this region. This area was steadily reduced by natural and man-caused factors to approximately 750,000 acres by 1865. In the ensuing 30 years, fires, insect and disease outbreaks, and logging reduced this area to about 225,000 acres (Hopkins 1899). By 1920, virtually the entire spruce type had been cut over (Clarkson 1978).

According to Hopkins (1899) extensive red spruce mortality caused by bark beetles occurred during two distinct periods, one from 1882 until about 1886; and another from 1890 to 1893. During the first period, mortality was attributed to an outbreak of a bark beetle, the four-eyed spruce beetle, *Polygraphus rufipennis* Kirby. This outbreak was precipitated by the disturbing influences referred to earlier, together with severe droughts and storms, "all (of which) contributed to favorable conditions for the multiplication of the species and its numerous allies, and the consequent destructive invasion." The second period of mortality was apparently caused by another bark beetle, the southern pine beetle, *Dendroctonus frontalis* Zimm. in combination with the four-eyed spruce beetle.

This series of events has produced the red spruce forests which occur in West Virginia today. The area the species occupies today is considerably reduced and the sites on which it grows have been altered by timber harvesting and fire.

The objectives of these surveys were to:

1. Determine the present location and extent of red spruce forests in West Virginia.
2. Estimate the basal area, numbers of trees, and volume per acre of healthy, declining, and dead red spruce.
3. Determine the status and condition of natural regeneration of red spruce and other commercially important species.
4. Characterize symptoms associated with dead and declining trees.
5. Identify insects and diseases associated with declining trees.

Aerial Photography

Forested areas containing red spruce were identified on high altititude panoramic color-IR photography and classified into three vegetation types and three mortality classes. Their locations were transferred to 1:24,000 scale USGS topographic maps, using a Bausch and Lomb zoom transfer scope, and the area of each stand was measured with a Numonics digitizer. A more detailed description of the multi-stage survey approach is described in Mielke et al. (1986).

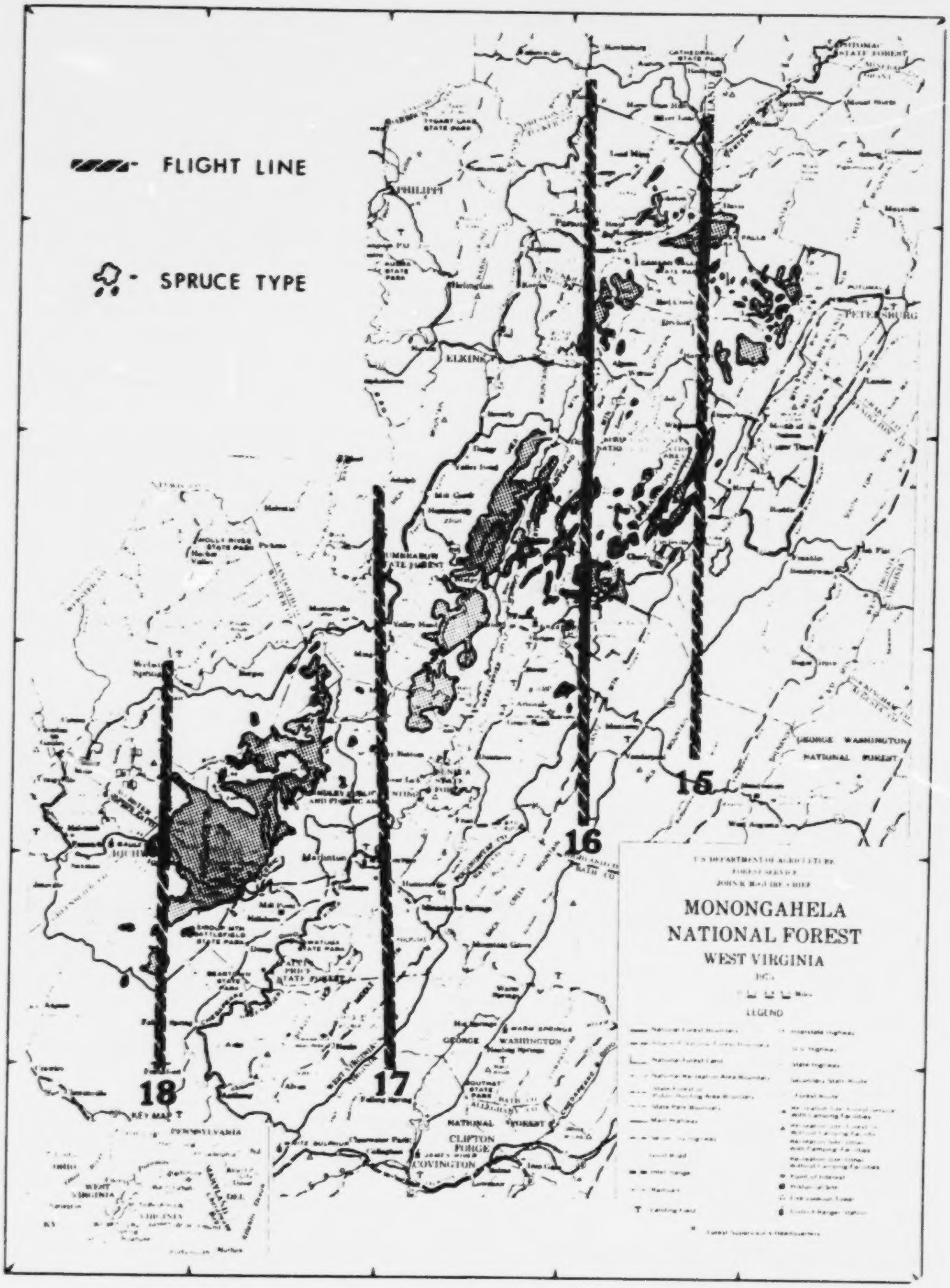
FLIGHT LINE
SPRUCE TYPE
15
16
17
18
PHILIPPI
ELKINS
PETERSBURG
GEORGE WASHINGTON
NATIONAL FOREST
CLIFTON FORGE
COVINGTON
KEY MAP
PENNSYLVANIA
WEST VIRGINIA
VIRGINIA
MONONGAHELA
NATIONAL FOREST
WEST VIRGINIA
LEGEND

Figure 1.--Aerial-photo flight lines and distribution of red spruce in West Virginia.

Vegetation types consisted of:

1. Conifer with a spruce component (>50 percent conifer)
2. Mixed wood with a spruce component (25-50 percent conifer)
3. Spruce plantation.

Mortality classes were defined as:

1. Light - <10 percent of the standing conifers dead or dying.
2. Moderate - 10-30 percent of the standing conifers dead or dying.
3. Heavy - >30 percent of the standing conifers dead or dying.

Similar vegetation types and the same mortality classes were used in an inventory of spruce and fir decline and mortality conducted in portions of New Hampshire, New York, and Vermont (Weiss et al. 1985).

Ground Data Acquisition

The primary ground sampling unit was a polygon. This was an area delineated on the aerial photos which was homogeneous with regard to vegetation type and mortality class. Within a stratum, polygons were selected for ground sampling using simple random selection without replacement. A minimum of 10 and a maximum of 30 polygons per stratum were selected for ground sampling. Strata were sampled at a rate designed to provide a 10 percent standard error of the mean for estimates of basal area, cubic foot, volume, and numbers of trees per acre.

There were some exceptions to the sample selection rule. A total of 44 polygons could not be classified into mortality strata because of film exposure problems. These were treated as a separate mortality stratum (unclassified) and 18 polygons were ground sampled. In addition, all polygons greater than 1,000 acres were ground sampled.

The total number of sample points per polygon depended on polygon area. Three sample points were established in polygons of 15 acres of less, 5 in polygons up to 1,000 acres, and 7 or 8 in polygons of greater than 1,000 acres. Points were located randomly in patterns which optimized coverage of each respective polygon. Points were placed a minimum of 2 chains apart in the smaller polygons and a minimum of 5 chains apart in polygons of 15 acres or larger.

Data Collection

Data were collected using 10 BAF variable radius plots in the mixed wood type, and 20 BAF variable radius plots in the conifer and plantation types. Data collected on the variable plot included dbh by 2 inch class of trees >5 inches dbh, and dbh by 1 inch class for trees ≤5 inches dbh, number of 8 foot logs to a minimum 9 inch top diameter, crown class, and tree condition. Tree condition was a visual assessment of the bole and crown. Trees were classified as healthy if they had greater than 40 percent live crown ratio and no signs of major bole injury or defect. Live crown ratio was defined as the ratio of live crown to total tree height, visually restoring gaps and dead or dying limbs with extant live limbs. Live trees with live crown ratios less than 40 percent were classified as declining. Specific reasons for decline (suppression, branch canker, snow breakage, heartrot, etc.) were noted. Only dead trees with at least their second order branches intact were classified as dead. Old dead trees with few or no main branches were ignored. Only dbh and species was recorded for all other tree species. Fifty-five dominant and co-dominant trees exhibiting the full range of symptoms were destructively sampled on nine intensive survey plots. Root, stem and foliar insects and diseases were enumerated.

The numbers of spruce and other commercially important seedlings and saplings were recorded at the center of the variable plot in a 1/1000 acre fixed radius plot. Subsequently, 1/16 acre strip plots (8.25 x 300 feet) were used to obtain more definitive data on the incidence of signs and symptoms on seedlings, saplings, and small poles.

Results

A total of 110,685 acres of forest land was classified as having a red spruce component (Table 1). Approximately 75 percent of the area was on the Monongahela National Forest, 20 percent on private lands within the Forest proclamation boundary, and 5 percent on other state or private lands (Figure 1). Area of light mortality comprised 86.5 percent of the total, 5.7 percent was moderate, and 1.5 percent heavy. Approximately 6.5 percent of the forest area classified as having a spruce component could not be classified into mortality strata because of film exposure problems. Most of this area was on Cheat Mountain and Shavers Mountain and was primarily private land.

The per acre values and their standard errors were computed based on polygon means. No estimate was made of the within polygon component of variance. Polygons over 1,000 acres in size were always measured, computation of means and standard errors were then adjusted. The standard errors reported in this paper are smaller than the true standard errors for this sample. The means however, remain unbiased.

Status of Decline and Mortality

In the mixed wood type, the volume, basal area and numbers of trees per acre of declining and dead spruce increase in the higher mortality classes. While some standard errors are large, the trend is clear and indicates a general concurrence with the photo classification. The volume, number of trees, and basal area per acre of healthy trees is lower in the heavy mortality class, but there is little difference between the light and moderate mortality classes (Table 2). In general, one would expect this relationship, assuming stocking levels are relatively uniform throughout the type (as the volume etc. of healthy trees goes up, the volume etc. of declining and dead trees goes down and vice versa).

Table 1.--Forest area with red spruce component by vegetation type and mortality class, determined from interpretation of high-altitude panoramic CIR aerial photographs--Mononghela National Forest and adjoining lands, West Virginia, 1985

Vegetation Type	Mortality class				
	Light	Moderate	Heavy	Unclassified	Total
	Acres				
Mixed wood	61,944	2,576	1,041	2,052	67,613
Conifer	31,936	3,718	562	5,119	41,335
Plantation	1,698	39	0	0	1,737
Total	95,578	6,333	1,603	7,171	110,685

This relationship is even clearer in the conifer type except for the lack of greater numbers of dead trees per acre in the higher mortality classes (Table 3). However, the volume and basal area per acre do increase in the higher mortality classes, suggesting that on the photography the size of dead trees influenced the classification of polygons into their respective mortality classes. There is less total volume per acre in polygons with heavy mortality. The values for spruce plantations have excessively high standard errors, and there was only one sample in the moderate mortality class (Table 4).

The total cubic foot volume, basal area, or number of red spruce on forest land classified as having a red spruce component in West Virginia can be estimated by combining the per acre data for all vegetation types (Tables 2, 3, and 4) and expanding them over the entire area (Table 1). This provides estimates of 96, 37 and 11 million cubic feet of healthy, declining, and dead red spruce in the state, respectively. Declining and dead trees represent 33 percent of the total volume of red spruce in the area.

On a relative basis, up to 82 percent of the spruce component of the conifer type was either dead or declining (Table 5), however, only a small proportion of the total population of spruce forest is affected by this high a level of damage.

The majority of red spruce basal area and volume per acre was in the pole and small sawtimber size classes. The majority of trees per acre was in the sapling and pole size classes. While the distribution of basal area, trees per acre, and volume by size class is expectedly nonuniform, the numbers of dead and declining trees as a percent of the total in each respective size class are remarkably similar, ranging from 30.3 percent to 46.6 percent for all categories in each size class (Table 6).

The numbers of red spruce seedlings and saplings increase with increasing levels of overstory mortality in both the mixed wood and conifer types (Table 7). This is an agreement with data from Weiss et al. (1985) for red spruce in the northeast. Red spruce regeneration was abundant throughout the survey area and seems to respond favorably to increased levels of incident light created by a declining and dying overstory. Whatever the causes of overstory decline and mortality, the regeneration remains visibly unaffected. Regeneration of other species was more abundant in the mixed wood type than in the conifer type. This is to be expected because there are greater numbers of other species present in the overstory of the mixed wood type.

Symptoms of Decline and Associated Biotic Agents

Declining red spruce were defined as trees having live crown ratios of <40 percent (Figure 2). Most saplings and some pole size trees that were declining were doing so because of suppressed crowns. The primary reason for the decline condition of crowns in the larger size classes was the occurrence of branch mortality initiated as either "branch dieback", mortality from branch tips progressing inward toward the base, or "branch flagging," defined as mortality of second and third order twigs nearer the base of a branch progressing outward and creating a tuft or flag of live foliage on branch ends. Both branch dieback and flagging symptoms can result in dead branches. Another symptom was a copious resin flow from branches that was visible from the ground. This was recorded as "branch canker."

A total of 1,059 declining spruce were evaluated on 142 plots. There were 99 saplings of which 45 (45 percent) were suppressed, as were 14 out of 517 (3 percent) pole sized trees. Branch dieback, flagging, and cankers accounted for the symptoms observed in 667 out of 1,059 (63 percent) declining trees. A total of 326 of 1,059 (31 percent) of declining trees were not associated with a readily identifiable symptom or causal agent (Table 8).

The fungus, *Valsa kunzei* Fr. (pycnidial stage = *Cytospora kunzei* Sacc.) was consistently found associated with symptomatic branches of declining crowns. Other fungi of lesser or undetermined pathogenicity also were found. In addition, all dead, declining, and healthy trees that were destructively sampled (N = 55) had one or more crown symptoms associated with *V. kunsei*; including branch dieback, flagging, heavy resin flow, or staining in the bark and cambium. Pycnidial fruiting bodies also were found, however, they and stain can be seen only on close inspection. This suggests that the symptom called "live crown ratio <40 percent" (Table 8) could be associated with *V. kunzei*. If it is, as many as 993 of 1059 declining trees (94 percent) may have symptoms attributable to *V. kunzei*. Also, declining trees had extensive fine feeder root mortality and fewer mycorrhizae as compared to healthy trees. Root disease caused by *Armillaria mellea*, Vahl. es Fr. and *Scytinostroma (Corticium) galactinum* (Fries) Donk were found only to a limited extent, and were usually on sites with poor drainage. All dead trees and some severely declining trees had been attacked by the four-eyed spruce beetle, *Polygraphus rufipennis*.

Table 2.--Mean volume, number of trees, and basal area per acre of healthy, declining, and dead red spruce ≥5 inches dbh in the mixed wood type--Monongahela National Forest and adjoining lands, West Virginia, 1985

Tree Condition	Mortality class			
	Light	Moderate	Heavy	Unclassified
Healthy				
Volume [a]	499.67 ± 68.89[b]	572.68 ± 72.45	348.38 ± 22.13	387.38 ± 113.19
Trees/acre	51.22 ± 7.41	61.67 ± 7.36	46.81 ± 7.25	121.28 ± 36.28
BA/acre	22.36 ± 2.93	29.21 ± 3.24	18.00 ± 1.47	24.50 ± 6.14
Declining				
Volume	190.03 ± 26.23	252.26 ± 36.06	498.00 ± 50.54	103.63 ± 34.08
Trees/acre	16.71 ± 2.23	29.18 ± 5.37	48.82 ± 7.12	37.97 ± 12.36
BA/acre	9.14 ± 1.16	12.21 ± 1.61	25.13 ± 2.63	7.00 ± 2.23
Dead				
Volume	76.30 ± 9.67	78.63 ± 18.15	178.25 ± 10.57	26.13 ± 7.65
Trees/acre	14.83 ± 4.00	15.42 ± 4.72	50.13 ± 12.60	10.38 ± 3.50
BA/acre	3.94 ± 0.49	4.21 ± 0.95	11.25 ± 0.97	2.13 ± 0.64
Total				
Volume	766.00 ± 91.17	903.58 ± 103.30	1024.63 ± 58.27	517.13 ± 149.89
Trees/acre	82.76 ± 11.21	106.26 ± 13.27	145.75 ± 22.99	169.63 ± 49.09
BA/acre	35.44 ± 3.86	45.63 ± 4.48	54.38 ± 3.85	33.63 ± 8.70

[a] Cubic-foot volume, trees per acre, and basal area per acre computed using SILVAH (Marquis et al. 1984).

[b] ± one standard error of the mean.

Table 3.--Mean volume, number of trees, and basal area per acre of healthy, declining, and dead red spruce ≥5 inches dbh in the conifer type--Monongahela National Forest and adjoining lands, West Virginia, 1985

Tree Condition	Mortality class			
	Light	Moderate	Heavy	Unclassified
Healthy				
Volume [a]	1492.97 ± 168.01[b]	1460.24 ± 208.05	321.80 ± 37.53	1403.30 ± 280.56
Trees/acre	283.04 ± 27.85	184.51 ± 51.48	54.94 ± 10.02	336.38 ± 78.87
BA/acre	89.22 ± 8.90	72.65 ± 11.52	17.50 ± 1.98	76.30 ± 9.81
Declining				
Volume	537.79 ± 108.25	962.12 ± 116.25	1066.40 ± 88.65	492.10 ± 160.84
Trees/acre	99.77 ± 17.58	99.96 ± 12.64	145.47 ± 20.03	45.02 ± 12.58
BA/acre	29.04 ± 5.19	46.82 ± 5.84	57.30 ± 5.15	23.00 ± 6.98
Dead				
Volume	120.01 ± 26.25	363.35 ± 108.88	433.30 ± 42.40	155.40 ± 54.21
Trees/acre	125.25 ± 23.67	58.88 ± 16.66	105.20 ± 13.34	46.30 ± 15.28
BA/acre	13.60 ± 2.25	19.06 ± 5.12	28.50 ± 2.69	9.70 ± 3.25
Total				
Volume	2150.77 ± 253.62	2785.71 ± 242.64	1821.50 ± 108.86	2050.80 ± 410.83
Trees/acre	508.06 ± 51.73	343.35 ± 56.35	305.60 ± 39.51	427.70 ± 72.05
BA/acre	131.80 ± 13.43	138.53 ± 12.38	103.30 ± 7.12	109.00 ± 15.69

[a] Cubic-foot volume, trees per acre, and basal area per acre computed using SILVAH (Marquis et al. 1984).

[b] ± one standard error of the mean.

Table 4.--Mean volume, number of trees, and basal area per acre of healthy, declining, and dead spruce in plantations--Monongahela National Forest and adjoining lands, West Virginia, 1985

Tree condition	Mortality class	
	Light	Moderate
Healthy spruce		
Volume [a]	1195.55 ± 367.00[b]	2317.00[c]
Trees/acre	313.20 ± 107.18	745.36
BA/acre	72.18 ± 22.03	153.00
Declining spruce		
Volume	50.00 ± 28.00	316.00
Trees/acre	4.62 ± 2.40	101.64
BA/acre	2.36 ± 1.34	20.00
Dead spruce		
Volume	7.18 ± 6.44	252.00
Trees/acre	5.27 ± 3.35	68.00
BA/acre	0.72 ± 0.46	17.00
Total		
Volume	1252.73 ± 380.27	2885.00
Trees/acre	323.09 ± 108.78	915.00
BA/acre	75.27 ± 22.60	190.00

[a] Cubic-foot volume, trees per acre, and basal area per acre computed using SILVAH (Marquis et al. 1984).
[b] One standard error of the mean.
[c] Only one area of moderate mortality was classified.

Table 5.--Proportion per acre of red spruce trees ≥ 5 inches dbh by tree condition, vegetation and mortality classes--Monongahela National Forest and adjoining lands, West Virginia, 1985

Vegetation		Mortality Class			
	Tree Condition	Light	Moderate	Heavy	Unclassified
Mixed wood	Healthy	62.01	58.04	32.22	71.50
	Declining	19.98	27.45	33.49	22.38
	Dead	18.01	14.51	34.39	6.12
Conifer	Healthy	55.96	53.73	17.98	78.65
	Declining	19.52	29.12	47.60	10.53
	Dead	24.52	17.15	34.42	10.82
Plantation	Healthy	96.94	81.46	--	--
	Declining	1.43	11.11	--	--
	Dead	1.63	7.43	--	--

Table 6.--Mean basal area, number of trees, and volume per acre of healthy and dead and declining red spruce by size class--Monongahela National Forest and adjoining lands, West Virginia, 1985

Size class	Basal Area (ft^2)		No. trees per acre		Cubic-foot volume	
	Healthy	Dead and declining	Healthy	Dead and declining	Healthy	Dead and declining
	Number					
Sapling (1.0-5.5 inches)	3.81 (51.9)[a]	3.49 (47.6)	60.18 (53.2)	52.97 (46.8)	0	0
Pole (5.5-11.5 inches)	22.03 (56.0)	17.32 (44.0)	73.38 (58.1)	53.01 (41.9)	385.54 (55.3)	311.76 (44.7)
Small sawtimber (11.51-17.5 inches)	18.42 (67.1)	9.05 (32.9)	18.99 (67.2)	9.25 (32.8)	422.79 (68.3)	196.54 (37.9)
Medium sawtimber (17.51-23.5 inches)	4.40 (69.7)	1.91 (30.3)	1.98 (65.1)	1.06 (34.8)	97.87 (64.1)	54.82 (37.9)
Large sawtimber (>23.5 inches)	0.70 (62.5)	0.42 (37.5)	0.20 (64.5)	0.11 (35.5)	18.71 (62.2)	11.36 (37.8)
Total	49.4 (60.5)	32.2 (39.5)	153.7 (56.9)	116.4 (43.1)	924.9 (61.7)	574.5 (38.3)

[a] Numbers in parentheses are percentages.

Table 7.--Number of seedlings and saplings (≥6 inches tall and <5 inches dbh) per acre by vegetation type and mortality class--Monongahela National Forest and adjoining lands, West Virginia, 1985

Species	Vegetation and mortality class									
	Mixed Wood				Conifer				Plantation	
	Light	Mod.	Heavy	Unclass.	Light	Mod.	Heavy	Unclass.	Light	Mod.
Red spruce	1991 ±171[a]	3067 ±517	4267 ±555	1317 ±417	3105 ±814	7000 ±1685	8715 ±2237	15500 ±4946	30 ±27	1800
other commercial species	2387 ±397	1913 ±203	1075 ±154	2450 ±443	1065 ±518	845 ±249	960 ±229	1705 ±855	303 ±243	800

[a] ± one standard error of the mean.

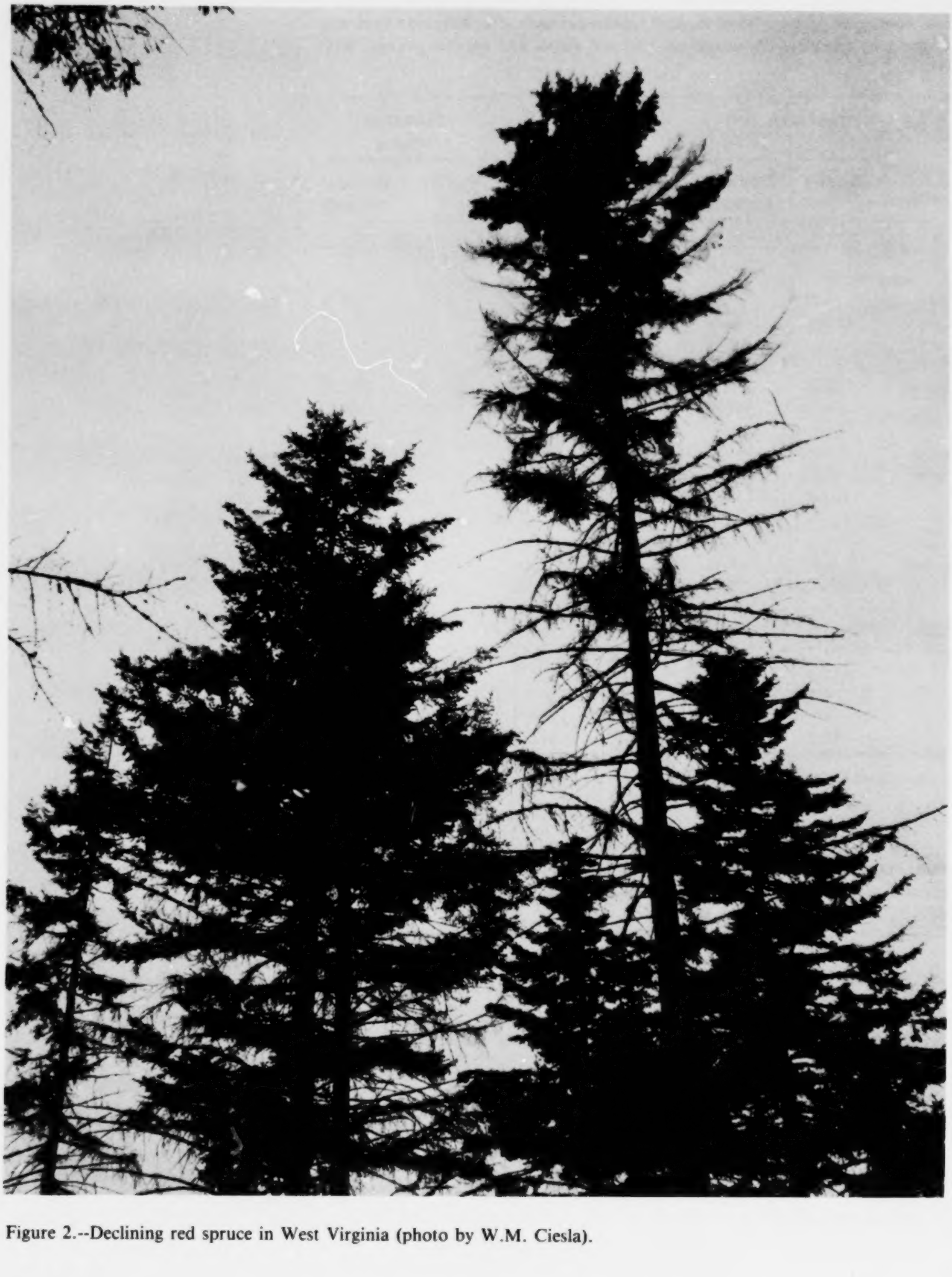

Figure 2.--Declining red spruce in West Virginia (photo by W.M. Ciesla).

Table 8.--Number of declining red spruce by symptom class and tree size class--Monongahela National Forest and adjoining lands, West Virginia, 1985

Size class	Number examined	Symptom								
		Live crown ratio <40%[a]	Branch dieback (BD)	Branch canker (BC)	Suppression	Branch flagging (BF)	Defective bole	BD + BC	BC + BF	BD + BF
Sapling (1.0-5.5 inches)	99	33(33)[b]	15(15)	1(1)	45(45)	0	1(1)	4(4)	0	(0)
Pole (5.51-11.5 inches)	517	204(39)	190(37)	49(9)	14(3)	1(1)	3(1)	53(10)	3(1)	(0)
Small sawtimber (11.51-17.5 inches)	252	55(22)	122(48)	21(8)	(0)	4(2)	1(1)	47(19)	2(1)	(0)
Medium sawtimber (17.51-23.5 inches)	133	30(23)	48(36)	14(11)	(0)	2(2)	2(2)	35(26)	1(1)	1(1)
Large sawtimber (>23.5 inches)	58	4(7)	20(35)	12(21)	(0)	3(5)	(0)	18(31)	1(2)	(0)
Total	1059	326(31)	395(37)	97(9)	59(6)	10(1)	7(1)	157(15)	7(1)	1(1)

[a] No other symptoms readily visible.

[b] Numbers in parentheses are percentages.

Discussion

There are approximately 110,685 acres of forest land with a red spruce component in West Virginia today. Approximately 37 percent of this area is of a vegetation type in which at least half of the trees are conifers. This vegetation type occurs at the highest elevations in this state and is presumably a pure or nearly pure red spruce forest. Sixty-one percent of the area was classified as a mixed wood type which contains a sizeable proportion of hardwoods. The conifer component of this type may be either red spruce or eastern hemlock with the proportion of eastern hemlock increasing with decreasing elevation. Only about 7 percent of the total area of spruce type in West Virginia currently has greater than 10 percent mortality. However, approximately 35 percent of the red spruce basal area, 40 percent of the number of trees, and 33 percent of the volume in the state is either dead or declining. The primary criteria for rating a tree as "declining" was a visual assessment of crown vigor.

The primary symptom associated with declining red spruce in the larger size classes was branch mortality. The fungus *Valsa kunzei* was commonly associated with this mortality. *V. kunzei* is pathogenic to many conifers and can be especially disfiguring and even fatal to red and Norway spruce (Waterman 1955). In most cases, however, spruce must first be predisposed by an environmental stress, in particular, winter injury and drought, before *V. kunzei* can successfully attack (Lavallee and Bard 1978; Schoeneweiss 1983; Waterman 1955). This fungus was the most frequent reason for crown of trees of larger size classes being classified as declining. Growth rates of severely infected trees are probably also affected. While no extensive growth ring analyses were conducted, the overall assessment of declining crowns in this survey suggests that branch infection by *V. kunzei* may be contributing to the reported growth trend decline in West Virginia (Adams et al. 1985).

In photographs taken during the period 1870-1920 (Clarkson 1975), the condition of some red spruce crowns appears similar to those of declining red spruce observed during this survey. This suggests that the current presence of *V. kunzei* may not be a new phenomenon, although its level of severity may be. Whether growth rates were also declining during that period is not known. It is possible that the chemical climate in West Virginia in recent times has predisposed spruce trees to infection by *V. kunzei*. Also, spruce is a shade tolerant tree and will often grow slowly in the understory for many years before being released. It will also slow down in radial growth under increasing competition, particularly under unmanaged conditions. Therefore, the age/diameter relationship can vary from stand to stand.

The extensive timber harvesting and associated fires which occurred around the turn of the century may have had some long term deleterious effect on the growth potential of those sites now supporting spruce, including the ability of sites to carry individual spruce for the 300+ years they can live. In the heavy mortality class of the conifer type there are fewer total healthy, declining and dead spruce per acre, less basal area, and volume per acre. This suggests that some intrinsic site factor may be contributing to the higher levels of mortality and lower productivity exhibited there.

If air pollution is to be considered as the primary cause for the decline and mortality of red spruce in West Virginia, there must also be some explanation for the apparent lack of decline symptoms on the red spruce regeneration which is presently abundant and thriving. Whatever the cause or combination of causes responsible for the decline and mortality of the red spruce overstory in West Virginia, this survey adds to the body of information describing its existence.

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Coastal Red Spruce Health Along an Acidic Fog/Ozone Gradient

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Abstract

South to mid-coast Maine forests are subjected to acidified fog and ozone at levels which exceed those reported for montane spruce forests in the eastern United States. Coastal fog is probably 10 times more acidic that it was 46 years ago, and is likely a result of nitrate rather than sulphate changes. At certain coastal sites, red spruce is showing forest decline symptoms similar to those observed in the Black Forest of Germany. Symptoms seem to be most developed in open stands with rough canopy on shallow, well-drained, low pH soils. Magnesium in soil and foliage is not limiting, but foliar phosphorous levels are low in symptomatic trees. Tree-ring analysis does not separate symptomatic from asymptomatic trees. From observation and experimentation corticolous lichens seem to be damaged by acidic fog.

Introduction

Along the coast of Maine during the summer months surface wind movement is from the S to SW over 50% of the time. This warm moist flow gives rise to frequent fog events as the air masses move over cold Gulf of Maine waters. The stability induced in the boundary layer flow by the cold surface waters inhibits vertical mixing processes, allowing surface emitted air pollutants from within the Northeast metropolitan coastal zone to remain concentrated as they travel for great distances over Gulf of Maine waters. As these pollutants reach the coast of Maine, they can (1) interact directly as gaseous pollutants with the land mass vegetation, or (2) modify the chemistry of fog events.

This paper summarizes evidence for (1) a fog acidity/ozone gradient along the coast, (2) historical changes in fog pH and ionic composition, (3) red spruce and associated corticolous lichen health problems at sites with high pollutant levels, and (4) preliminary data on soil and foliar nutrient and chlorophyll levels.

The Pollutants

Fog and rain samples have been collected along the coast of Maine for the years 1985, '86, '87 during the months of June through October. In 1985 four coastal sites and one high elevation inland site (Sugarloaf Mountain, elevation 1291 M) in Maine were sampled. The number of coastal sites was expanded to six in 1987 and these monitor fog/rain events along a 350-mile SW to NE gradient from the New Hampshire border to just beyond the Canadian border in the Province of New Brunswick.

Rain was collected using previously described methods (Jagels and Gordon 1986), and pH for 1987 is summarized in Table 1. Differences between sites are small and no gradient can be discerned.

Fog was sampled using CWP Active Cloud Water collectors (Daube et al. 1987) which collect fog droplets on a removable cartridge of 0.78 mm diameter Teflon strands, using a design which excludes most rain droplets ≥ 200 μm at windspeeds ≤ 10 m/s. Fog water pH was measured in the field and again at the University of Maine. Samples were analyzed for Ca^{++}, Mg^{++}, K^{+}, Na^{+}, NH_4^{+}, $SO_4^{=}$, NO_3^{-} and Cl^{-} using procedures of Hillman et al. (1986). The chemistry was corrected for marine aerosols using Mg^{++} as a reference species (Keene et al. 1986).

Table 1.--Rain pH, 1987

	Site	No. of samples	Mean pH derived from H^+ concentration	Minimum pH	Maximum pH
SW	Appledore Island	8	4.06	3.45	6.11
↓	Cape Elizabeth	16	4.24	3.88	5.35
	Damariscove Island	10	4.21	3.90	5.16
	Isle au Haut	15	4.04	3.53	5.04
	Roque Island	11	4.36	3.86	5.23
NE	Kent Island	16	4.19	3.72	4.85

Table 2 summarizes the fog pH data for 1987. Unlike the rain sampling, a decreasing gradient of acidity along the coast from SW to NE can be seen from Cape Elizabeth to Kent Island. Appledore Island is an exception in the gradient pattern; perhaps because it is so close to Boston that atmospheric chemical reactions have not been completed, or possibly because Cape Ann diverts pollutants away from this site. From Portland to the mid-coast (Isle au Haut) fog is particularly acidic, with several events each season having pH values below 3.0. Farther northeast (Roque Island and Kent Island, N.B.) the fog is less acidic and pH values rarely drop below 3.3

Table 2.--Fog pH, 1987

Site	No. of samples	Mean pH Derived from H$^+$ concentration	Minimum pH	Maximum pH
SW Appledore Island	4	3.45	3.09	6.49
Cape Elizabeth	3	2.84	2.56	3.62
Damariscove Island	5	2.73	2.38	3.69
Isle au Haut	10	3.25	2.70	3.97
↓ Roque Island	5	3.50	3.34	3.73
NE Kent Island	13	3.63	3.09	5.76

Table 3 summarizes pH, sulphate and nitrate for Whiteface Mountain, New York, Sugarloaf Mountain, Maine, and the coast of Maine. For each site the sulphate levels are roughly comparable, especially considering that the Whiteface data covers more years and includes winter as well as summer monitoring. The nitrate value at Whiteface is roughly double that of Sugarloaf Mountain. This difference may be due to an enhancement of NO$_3^-$ in the winter. Nitrate values for summer monitoring at Whiteface (Castillo et al. 1983) were 84 μeq l^{-1}.

Table 3.--High elevation cloud compared to coastal fog

Site	pH	μeq l^{-1} SO$_4$	μeq l^{-1} NO$_3$
Whiteface[a]	3.7	640	189
Sugarloaf	3.40	500.09	97.79
Maine Coast	3.36	481.54	347.54

[a] Personal communication from Volker Mohnen, Atmos. Sci. Center, SUNY, Albany, NY.

The nitrate levels for the coast of Maine (which are only summer values) are considerably higher than for the two high elevation sites. A single fog event monitored at Bar Harbor, Maine, in November 1984 (Weathers et al. 1986) had a nitrate level of 4580 μeq l^{-1} suggesting that winter levels of nitrate might be even higher. Cluster analysis showed that the most acidic fogs were associated with high nitrate loading on the coastal sites, but not at Sugarloaf Mountain (Kimball et al. 1988).

The high nitrate levels in fog on the coast of Maine are consistent with ozone levels reported for the state, which are highest within the coastal corridor. Hourly ozone averages in the south coast region can exceed 0.17 ppm, and for all parts of the coast, ozone levels generally exceed inland industrial, urban or rural sites. From monitoring data and trajectory analysis only a small portion of the ozone values are attributable to local sources within the state (Emery 1986).

During the summer of 1987 an ozone monitor was placed on Isle au Haut, one of our forest monitoring sites, and a peak hourly average of 0.155 ppm was recorded. With such elevated levels of ozone and nitrate, the potential for excess levels of other photooxidants is also high, but we have no direct evidence to support this presumption. SO$_2$ levels have been measured by the state Department of Environmental Protection and are generally low -- below 0.1 ppm for 3 hour maximums (Emery 1986).

We have no historical data for ozone levels prior to 1979. However, fog was collected in the late 1930's and pH was measured as well as sulphate -- using a barium chloride turbidimetric method (Houghton 1955). On most of the coastal New England sites where fog was collected, a nickel plated screen was the collection surface. But on one site, Brooklin, Maine, a stainless steel screen was used. We have recently checked one of the original nickel plated screens and find that it affects the pH of impacted water. In a test run, the screen was first rinsed and then distilled water with a pH of 5.56 was sprayed onto the screen. Effluent water had a pH of 8.83. On two subsequent sprayings the pH was 7.90 and 7.20. Chemical analysis revealed that nickel had been oxidized, presumably by sea salt between collections, and was contaminating the samples.

We conclude, therefore, that the near neutrality pH values recorded in the late 1930's (Houghton 1955) for fog collected on these nickel plated screens is erroneous. The fog pH values for Brooklin, Maine, collected on a stainless steel screen are probably closer to being accurate for the period. The average pH for Brooklin, Maine, was 4.7 (range of 3.5 to 6.3). Brooklin is close to our Isle au Haut site (average fog pH 3.35). Sulphate levels for Brooklin in 1939 were 290 μeq l^{-1} while for Isle au Haut, 1985 sulphate levels were 194 μeq l^{-1} (range 139-250). Thus, sulphate levels appear to have changed little in 46 years. Nitrate was not measured by Houghton. We tentatively conclude that the greater than 10 fold increase in acidity during the past 46 years is due primarily to increases in nitrate, as a consequence of NO$_x$ pollution.

The Forests

Casual observation reveals that red spruce trees have foliar symptoms suggestive of declining trees at various locations along the coast. In 1986 we chose four sites for intensive study over several years. Two of these sites are on Isle au Haut where fog acidity and ozone levels are high. The two sites are presumably similar in terms of ozone exposure, but one site (Head Harbor) has an open, rough canopy red spruce stand while the other (Eastern Head) has a closed stand with a more even canopy. Based on modeling considerations (Lovett 1984) and actual measurement the open, rough canopy stand intercepts more fog. In the closed stand much of the fog is captured by the white spruce which occupy the shore zone.

A third site is on Roque Island where fog acidity and ozone levels are lower. The stand is closed but has a rough canopy. The fourth site is at the University Forest, Orono. This stand has a closed canopy and it outside the coastal fog zone and receives considerably lower ozone levels.

Declining red spruce on Isle au Haut display a chlorosis of second year or older needles with yellowing confined primarily to the upper, sun-exposed, surfaces. Premature needle loss from oldest to younger needles is found primarily in the upper third of the crown. At later stages a live "stork's nest" top may persist while the remainder of the upper crown has shed all needles. Neoformed (also termed latent, epicormic or adventitious) shoots with green needles develop from the dorsal surface of branches with chlorotic foliage. These neoformed shoots have an upright rather than the normal lateral orientation of branches (Jagels 1986). In general the symptoms resemble those seen on Norway spruce in the Black Forest of Germany (personal observations).

In April of 1987 reddish-brown needle necrosis was observed on current shoots of red spruce on the Eastern Head site (where trees have previously been asymptomatic). A warm spell in late February and early March, while the ground was still frozen, may have triggered this event. The trees on the Head Harbor site did not display this symptom.

A search for pathogens or insect pests has failed to reveal any consistent biotic causal agents. Mistletoe and spruce tip moth are found on white spruce on the island, and rarely one finds a leaf rust *(Chrysomyxa)* on red spruce. Fruiting body evidence for root rot has not been seen, but a more thorough examination of root systems would be needed to rule out "stand opening disease" *(Inonotus tomentosus)* on Head Harbor. Spruce canker *(Leucostoma kunzei)* has not been observed. A very few late stage symptomatic trees have sapsucker damage indicating the possible presence of bark beetle.

The soils on all sites are relatively shallow, high in organic content and lie over granite or hardpan. On Isle au Haut soils are somewhat excessively drained, on Roque Island they are well drained, and at the University Forest they are moderately drained. Soil features are summarized for the four sites in Table 4 (horizons 01 and 02 combined). These data would suggest that soil depth or pH are not influencing factors in the development of decline symptoms. From a comparison of Ca, Al and percent base saturation between Head Harbor (symptomatic) and Eastern Head (asymptomatic), one could conclude that these were contributing factors. Roque Island and University Forest sites also have low base saturation levels, but they also have lower pollutant levels. Levels of soil Mg do not seem to be a factor.

Table 4.--Soil depth and forest floor exchangeable element concentrations (meq/100g)

Site	Depth	pH	% Base Saturation	Ca	Mg	Al
	cm					
Head Harbor	22	4.15	33	4.70	7.15	10.55
Eastern Head	14	4.05	72	12.90	8.55	2.85
Roque Island	28	4.10	39	9.20	3.60	15.30
Univ. Forest	14	3.80	26	5.25	1.70	17.50

Analysis of foliage is summarized in Table 5. Magnesium seems to be well above deficiency levels in all trees. A phosphorus deficiency is possible in the Head Harbor trees, and calcium is low in first year needles of these trees; but aluminum levels are comparable or only slightly higher than in trees from the other sites. This is an initial analysis and we are presently sampling at regular intervals throughout the year.

Table 6 shows some preliminary data for chlorophyll and moisture content of needles from three of the four sites. As expected the needles from the symptomatic Head Harbor site had the lowest chlorophyll content. Third year needles contained more total chlorophyll than first year needles on both fresh and dry weight bases. These results are very preliminary and we are continuing an expanded pigment analysis at regular seasonal intervals. The moisture content data (Table 6) suggests that third year needles at both sites on Isle au Haut are under greater moisture stress than is the case for University Forest trees.

Analysis of tree rings on the four sites (Jagels 1987) indicate that growth reductions began simultaneously in the mid 1950's at Head Harbor and the University Forest and a nearly synchronous pattern of reduced growth rate has continued on these two sites to the present. Radial increment reduction at Eastern Head began in the early 1960's but is less pronounced on this site. On Roque Island radial increment reduction did not begin until the late 1970's. This data suggests that radial increment reduction is not a reliable indicator of spruce decline, but rather, as a secondary tree response, can reflect one or more disparate environmental factors.

Table 5.--Foliar chemistry in ppm (values for N are percentages)[a]

Element	Head Harbor		Eastern Head		Roque		Univ. Forest	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
N	1.00	0.95	1.19	1.18	1.24	1.06	1.13	0.91
Ca	808	2483	2283	4288	2286	5005	2714	3665
K	5741	4985	5560	5768	7183	5540	6448	5713
Mg	992	878	960	990	1129	904	1222	1146
P	918	770	1444	1474	1411	1131	1705	1551
Al	55	74	34	44	40	52	57	64
B	14	12	13	14	16	19	14	11
Cu	3	2	3	2	3	2	2	2
Fe	66	83	36	39	76	43	44	42
Mn	846	924	606	887	622	794	787	879
Na	103	210	95	100	49	97	43	42
Zn	21	26	22	25	23	31	19	19

[a] Five trees per site sampled; 3 branches per tree from south side of upper ¼ crown.

Table 6.--Average chlorophyll and moisture content of red spruce first and third year needles

Site	Fresh wt. basis		Dry wt. basis		Moisture content		
	First year	Third year	First year	Third year	First year	Third year	Diff.
			mg/g tissue		------*Percent*------		
Head Harbor	0.87	1.09	1.87	2.11	52.8	46.8	6.0
Eastern Head	1.16	1.69	2.66	3.4	54.6	48.8	5.8
Univ. Forest	1.37	1.69	3.22	3.95	58.0	56.0	2.0

Corticolous lichens have been examined on all four sites. On Isle au Haut *Platismatia glauca*, *Usnea subfloridana* and *Hypogymnia physodes* display symptoms of either leaching of lichen acids or degradation of photobiont chloroplasts (pinkish, blackened or bleached thalli). On Roque Island some color changes have been observed, but in general the lichens are considerably healthier than on Isle au Haut. At the University Forest only minor discolorations have been observed.

During the summer of 1987 selected corticolous lichens were periodically misted (500 ml applied 5 times during September and October) with distilled water which had been acidified (pH = 1.0) with either H_2SO_4 or HNO_3. Acidified misting induced color changes and bleaching which mimic field observed symptoms. For at least one species, *Parmelia sulcata*, HNO_3 acidified mist had a more adverse impact than H_2SO_4 acidified mist. Follow-up experiments with less acidified misting are planned.

Summary and Conclusions

Spruce forests along the southwestern half of the coast of Maine are subjected to acidified fog and ozone at levels which exceed those reported for any high elevation spruce forests in the Eastern United States. Qualitatively the acid fog differs from high elevation cloud-fog in having higher nitrate levels. Historically, coastal fog has probably become at least ten times more acidic then it was 46 years ago, and this increased acidity is most likely due to nitrate rather than sulphate increases. Although historical data for ozone is lacking, the suggested increase in nitrate levels have probably resulted in parallel ozone increases during the past half century.

Red spruce on certain sites along the coast of Maine is showing forest decline symptoms similar to those observed on Norway spruce in the Black Forest of Germany. Biological disease agents have not been completely ruled out, but at present do not seem to be the be the primary cause. The soil on which the decline is most manifest has low pH (around 4.0) and low percent base saturation. But an inland site, away from pollutant loading, has similar soil characteristics, but no visible decline symptoms are observed. Both soil and foliar analysis reveal that magnesium does not seem to be a limiting factor as has been reported for German forests (Prinz et al. 1982). Needles from symptomatic trees have reduced levels of phosphorus and show a possible moisture stress. Tree-ring analysis proved uninformative in separating symptomatic from asymptomatic trees. Observation and experimentation with corticolous lichens suggests that they are being impacted by acidic fog.

At present no definitive conclusions are possible, but a pattern of correlation between symptomatic trees and airborne pollution is emerging, particularly for open, rough canopy stands on poor soils.

Acknowledgements

This research has been funded by U.S.D.A. (McIntire-Stennis), U.S. Department of Interior (U.S.G.S.) and The Andrew W. Mellon Foundation. Maine Agricultural Experiment Station, Report No. 1327.

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Preliminary Report on Red Spruce Decline in Massachusetts

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Abstract

In the spring of 1987, Massachusetts was incorporated into the Cooperative Survey of Red Spruce and Balsam Fir Decline and Mortality in the Northeast, a project sponsored by the U.S. Environmental Protection Agency and USDA Forest Service, Forest Response Program. As part of the Cooperative Survey, Massachusetts agreed to establish permanent symptomatology plots in the spruce forests of western Massachusetts using standardized procedures outlined in the Field Manual and Quality Assurance Documents prepared by the Forest Pest Management staff, USDA Forest Service, Durham, New Hampshire. This report summarizes our approach to the field projects initiated in 1987 and presents some preliminary findings.

Introduction

A multidisciplinary approach has been applied to the investigation of red spruce decline in Massachusetts. The primary research effort is directed at a comprehensive assessment of the symptomatology of the decline syndrome. This work is an integral component of the region-wide survey of red spruce *(Picea rubens)* and balsam fir *(Abies balsamea)* decline in the Northeast and is supported by the National Vegetation Survey, Forest Response Program (Weiss et. al. 1984). In addition, work is in progress to characterize the soils and investigate root-pathogen associations in declined areas. All current data will be evaluated within the context of historically important disturbance factors which may have influenced the current condition of the spruce forest type in Massachusetts.

In this report we will summarize our approach to the 3 projects initiated in 1987 on symptomatology, soil survey, and root-pathogen associations, and present some preliminary results. Our research team includes an air quality specialist, plant pathologist, soil scientist, and entomologist. It is our goal to study the red spruce in Massachusetts and to explain: (1) why they are declining, and (2) what role acid rain and associated air pollutants play in the decline process.

Site Characterization and Monitoring

The study area falls within Berkshire County, in the western part of the state, where spruce forests dominate at the higher elevations (between 1700 and 2500 ft.). Most of the virgin spruce forests are gone, having been logged or cut over for farms and pastures by the late 1800's. Todays spruce forest is second growth, coming in on abandoned upland fields, and is on average less than 80 years old. We found the most important companion species included birch *(Betula* spp.), red maple *(Acer rubrum),* and black cherry *(Prunus serotina)* in the overstory and striped maple *(Acer pennsylvanicum),* balsam fir *(Abies balsamea),* arrowood *(Viburnum dentatum),* shadbush *(Amelenchier* spp.), ferns and briars in the understory. The soils have developed from glacial activity and are generally rocky, shallow, and acidic (pH 4.0 to 5.5) with a thick mor humus.

Study plots were chosen at random from stands identified on aerial photos as greater than 5 acres in size and more than 50 percent spruce. Three of the 6 plots are located in Mt. Greylock State Reservation (the highest point in Massachusetts), and the remaining three are located to the south of Mt. Greylock along the eastern ridge of the Berkshire hills.

Two state-operated monitoring stations operate year round within the study area. Pollutants sampled include O_3, SO_2, and TSP. Precipitation and ozone data are also available from the summit of Mt. Greylock and a cloud chemistry monitoring unit will be operational next year.

Preliminary Results and Discussion

Symptomatology Project

At each of the 6 plots, site and stand characteristics were fully described, using standardized procedures (Millers and Miller-Weeks 1986), in order to gain a comprehensive picture of the declined area. The general condition of all red spruce trees >13 cm DBH was recorded and a subsample (20 trees/plot) selected at random to obtain detailed information on tree health, symptomatology, and foliar response. Some preliminary results are presented in Table 1.

Mortality rates were high (> 10%) in all plots, with dead trees occurring in pockets rather than scattered uniformly throughout the stand. Although visible signs were scarce, this pattern suggests infection and spread by an *Armillaria* - like pathogen moving through the soil. Loss of supporting roots due to infection by a root pathogen could also help explain the frequency of blowdowns in the study plots (Table 1).

On a large percentage of the sample trees, resinosis and swelling was visible on the main stem and less often on the branch samples. Laboratory analyses confirmed that these symptoms were associated with infection by *Fomes pini* and *Cytospora kunzei* respectively.

For the crown vigor classifications (Table 1), defoliation was a more significant factor than crown discoloration and there were very few cases where symptoms of either type occurred on more

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than 50% of the live crowns (i.e. moderate to severe damage according to Bauer 1985). Needle loss occurred first on the older branches in the lower crown.

An undiagnosed symptom referred to as "winter fleck" and described as white to tan lesions confined to the upper surface of the needles was visible on all branch samples. There was no sign of infection by the Eastern dwarf mistletoe *(Arceuthobium pusillum)* and no evidence of attack by the spruce beetle *(Dendroctonus rufipennis)*. Scattered patches of healthy spruce regeneration were common in 5 of the 6 study plots (Table 1).

The same plots and sample trees will be evaluated in 1988 and '89 to determine the progression of symptoms on the trees as the severity of damage increases overtime.

Root Disease Project

Root samples from declining and healthy red spruce in each plot were obtained over the course of the growing season. Laboratory isolations of the various fungi colonizing these roots have been carried out. Preliminary isolations have resulted in the identification of several species of *Fusaria, Armillaria* and possibly *Cylindrocladium*. Future work will involve further study and identification of fungi isolated from spruce roots. Pathogenicity tests of those fungi which may cause diseases of red spruce will be conducted. The role of ozone as a factor in the decline will be investigated through the exposure of red spruce inoculated with pathogenic fungi to chronic levels of the pollutant.

Soils Project

At each plot center, 3 soil pits were excavated and samples collected from the L, F, H, A, B upper, B lower, and C horizons, as well as the AE horizon where it existed. Additional samples were collected at the base of 2 trees from each plot with and without obvious decline symptoms. Laboratory analyses will determine pH (H_2O), pH ($CaCl_2$), available aluminum, sulfur, exchangeable cations, cation exchange capacity, and nitrogen. These data should provide a basis of comparison between soil characteristics and decline symptoms for plots and trees.

Acknowledgments

This project is supported by a grant from the Executive Office of Environmental Affairs, Massachusetts Department of Environmental Management, 100 Cambridge Street, Boston, MA 02202. Valuable assistance is provided by the Forest Pest Management Staff, USDA Forest Service, Durham, N.H. and by Dr. William Manning, Professor of Plant Pathology at the University of Massachusetts.

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Table 1.--Regeneration, percentage of healthy, declining, and dead trees, degree of damage from principal agents, and crown vigor on red spruce plots in Massachusetts, 1987.

Plot No.	Elevation	Age	Regeneration	Healthy	Declining	Dead	Blowdown	Trunk rot[a]	Armillaria root rot	Cytospora canker	Spruce gall aphid	Needle fleck	West German damage class	U.S. vigor class
	m	Years		*Percent*										
1	640	87	+ +[b]	71	13	16	+ +	+ +	-	+	+	+	2[c]	2[d]
2	704	64	+	51	18	31	-	+	+ +	-	-	+	2	2
3	735	68	+ +	76	12	11	+	+ +	+	-	+	+	2	2
4	683	68	+ +	61	8	33	-	+	+	-	-	+	1	2
5	527	65	+ +	58	2	41	+	+	+	-	+ +	+	1	2
6	707	78	-	72	9	20	-	+	-	-	-	+	1	2

[a] *Fomes pini.*

[b] - = not present; + = present; + + = abundant.

[c] Damage range in percent: 1 = 0-10; 2 = 11-25; 3 = 26-60; 4 = 61-99; 5 = dead.

[d] Damage range in percent: 1 = 0-10; 2 = 11-50; 3 = more than 50; 4 = dead.

Forest Decline Symptoms in a Norway Spruce Plantation in Massachusetts

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Abstract

Three hundred trees from a 76-year-old Norway spruce plantation in Colrain, Massachusetts were classified according to the standardized methods used for inventorying forest damage in air pollution studies in West Germany. The sample of trees generally showed little or no symptoms, but 4% had symptoms that caused them to be classified as "moderate to serious" damage or worse. Estimates of foliage density from ground-level assessment were consistent with direct measurement of branch and foliage weight for 4 trees from this sample. The pattern of loss of older foliage on the inner portions of the crowns is consistent with that observed in Germany. Other symptoms that sometimes occur in German spruce decline (foliage discoloration, proliferation of stress shoots, abscission of green shoots) were not observed in the sample trees.

Introduction

Since 1980, various symptoms of forest decline (known collectively as Waldsterben) have been reported for many trees species in Germany. These symptoms have been linked in part to the effects of air pollution (Schutt and Cowling 1985). Norway spruce *(Picea abies)* has been the focus of much of the attention in these studies largely because it is the most abundant tree species in Germany. For this reason, symptoms have been better described for this species than any other.

Reported symptoms affect roots, stems, and crowns, but since crown symptoms are the easiest to observe, they are the ones used in assessing forest damage on a national scale. These crown symptoms include (Anonymous 1984, Bauer 1985, Schutt and Cowling 1985): transparent tree crowns due to loss of foliage, beginning usually with the older needles on the pendant secondary branches; proliferation of adventituous shoots on the upper side of the branches; reduction in needle longevity from a normal 6 years to 3 or 4 years; casting of living shoots; and yellowing of needles, mainly on trees growing at high elevations, with the discoloration beginning on the upper sides of needles, and progressing from older foliage to younger and from lower branches to upper ones.

Casual observations of Norway spruce in roadside or urban sites in Massachusetts and Connecticut by foresters familiar with Waldsterben symptoms indicate that similar symptoms may occur on some trees here as well. Those symptoms are not necessarily comparable to widespread decline symptoms in Germany, since particular problems associated with those sites *(e.g.*, road salt, soil compaction, local air pollution) may be stressing the trees. Observations of spruce plantations in areas more remote from these local influences would be more valuable for such a comparison.

Most Norway spruce planations in the northeastern U.S. date to the 1930's, resulting from afforestation of abandoned farmlands by the Civilian Conservation Corps. These are presently in the 50- to 60-year age class, and so are just reaching the age when symptoms appear in German trees. However, a few older plantations do exist, one of them being a 30-ha stand planted in 1910 on the H.O. Cook State Forest in Colrain, Massachusetts. This stand provides an opportunity to examine whether Waldsterben symptoms described above are present in North America on a site remote from a direct source of pollutants.

The objective of this study was to classify a sample of Norway spruce trees in this Massachusetts plantation by the standardized forest decline inventory methods used in Germany, and then to examine more carefully the foliage of several trees of different decline classes for comparison with reported Waldsterben symptoms for spruce.

Stand Description

The H.O. Cook State Forest plantation is at 450-500 m elevation, on a gentle, southeast-facing slope. Trees were planted in spring of 1910 on an abandoned sheep pasture, using 4-year-old Norway spruce seedlings grown in a nursery in France. Only one light thinning has been made in part of the stand, so stem density remains high. Dominant trees average about 30 m in height and 35-40 cm in diameter at breast height, indicating the site provides excellent growing conditions for spruce.

Two harvest cuts were recently made in a part of the stand, each one consisting of a series of narrow strip clearcuts. One series was made in 1981, and the other in 1985. This provided an excellent situation for this study by exposing the crowns of forest-grown trees to full view (Fig. 1).

Methods

Observations were made in 1986, when the stand was 76 years old from time of planting. A sample of trees was chosen by selecting trees of the dominant or codominant crown classes that bordered the clearcut strips, except that trees with evidence of logging damage were omitted. The first 150 such trees encountered as the observer progressed along the edge of the strips cut in 1985 and the first 150 along the edge of the strips cut in 1981 were selected. These 300 trees were placed into one of 5 damage class categories used in the standardized damage inventory methods used throughout West Germany (Anonymous 1984, Bauer 1985).

By this classification method, yellowing of foliage causes a tree to be placed into a higher damage class than would be indicated by foliage density alone. Photographs of representative trees for each class taken from Ammer (1983) were transferred to acetate transparencies and taken into the field for comparison with each sample tree to assure consistency in assigning damage classes (Fig. 2).

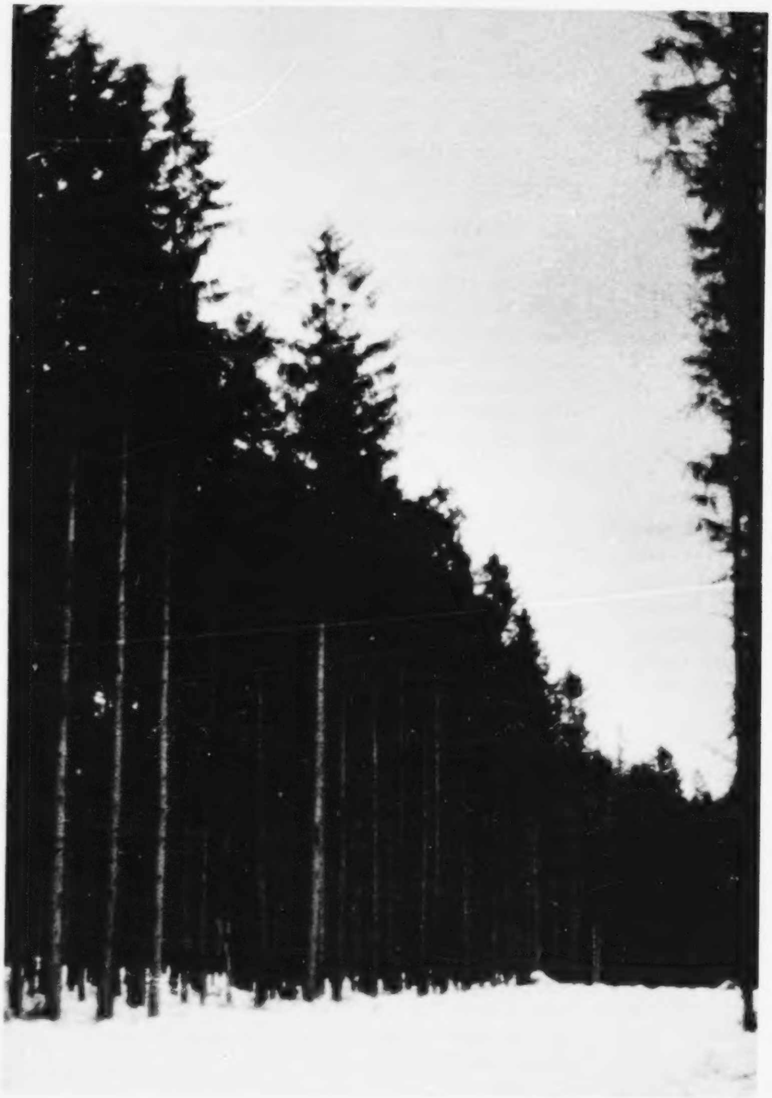
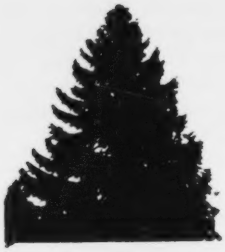
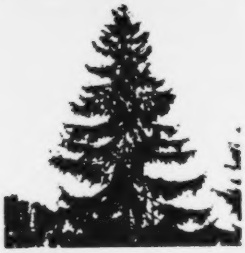


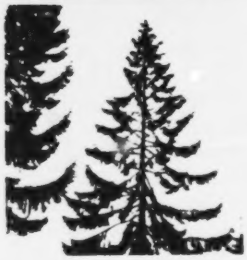
Figure 1.--View of clearcut strip in Norway spruce plantation at H.O. Cook State Forest, Colrain Massachusetts, showing border trees that constituted part of the sample for this study. Tree in center of photograph was rated as a damage class 2 (moderate to serious damage). The principal symptom is a transparent crown due to foliage loss on the upper, interior portion of crown. Compare to class 2 tree in Fig. 2.



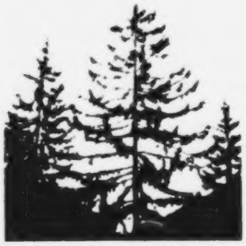
0: healthy
0-10% needle loss



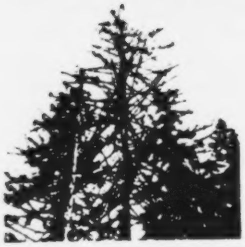
1: slight damage
11-25% needle loss



2: moderate to serious damage
26-60% needle loss



3: dying
more than 60% needle loss



4: dead
100% needle loss

Figure 2.--Photographs from Ammer (1983) illustrating the five damage classes used in forest damage inventories in West Germany. These photographs were used as field guide for assigning damage classificaitons for trees in the H.O. Cook plantation.

Four trees were then felled, 2 from damage class 0 (healthy) and 2 from damage class 2 (moderate to serious damage). For each tree, sample branches were chosen by selecting all branches from each whorl closest to the points 2, 3, 4, 6, 8, 10, and 12 m from the top of the tree (this included the entire length of the live crown). Fresh weight of each sample branch was measured at the site. One branch from each whorl was chosen by random sampling and was transported to the laboratory. Each branch of this subsample was cut into three components--pendant branches, adventitious shoots, and main branch including branch terminal shoots (Fig. 3). Each component was dried at 30 C for 48 hours, and needles were separated from wood and weighed.

Results and Discussion

Based upon ground-level observations, the majority of trees fell into damage classes 0 or 1, indicating a complete or nearly complete complement of foliage (Table 1). Only 4% of the 300 sample trees were in damage classes 2-4. No yellowing of foliage was observed, so all classification was on the basis of foliage density alone. The range of foliage densities included within classes 0 and 1 (0 to 25% needle loss) is of such low magnitude that for many trees these two classes could not be differentiated with confidence; thus, this distinction may not be important. Differences among other classes were clearly discernible. Foliage symptoms appeared to be restricted mainly to the upper portions of the crown.

Results from the 2 samples of trees differed in that the trees with crowns that had been exposed for 5 years by cutting of the adjacent trees had greatest numbers in the damage classes 2 to 4 than those with crowns exposed for only 1 year (Table 1). One possible explanation for this difference is a condition sometimes called "thinning shock" or "post-thinning decline". The positive effect of thinning is an increase in photosynthesis in the residual trees, which depends on the addition of new foliage. There is often a lag of several years while this foliage develops before photosynthesis increases markedly. The negative effect of thinning is an increase in stem respiration due to the higher temperature caused by increased sunlight on the stems. This effect occurs immediately. In some trees, especially those receiving an initial thinning at a fairly old age, the negative effects can outweigh the positive effects in the first few years after being exposed to added sunlight, leading to a decline in vigor or even death of residual trees during that time. It is possible that this may account for part or all of the decline symptoms seen in the H.O. Cook plantation.

Estimates of foliage loss from ground-level observations proved to be consistent with direct branch measurements for class 0 and class 2 trees. Total fresh weight of branches in the upper 4 m of the crown (approximately ⅓ of the live crown length) of class 2 trees was 40-60% of that of class 0 trees (Table 2). Below that height, branch breakage and suppression caused by crown competition with adjacent trees made branch size and structure very irregular, and branch weight was not significantly different between class 0 and class 2 trees. Needle dry weights of the subsampled branches followed the same trend as total branch fresh weight. In the upper 4 m of the crowns, branches from class 2 trees had 38% of the needle dry weight of those of class 0 trees (320 g foliage/branch for class 0, compared to 123 for class 2; n = 16 branches; t-test significant at $p<0.001$).

Needle ages could not be determined accurately beacuse many pendant shoots did not produce new growth each year. Maximum needle age was counted only on the main branch axes, where extension growth did occur each year. This varied mainly between 4 and 7 years, with no pattern of differences being apparent between class 0 and class 2 trees. However, the fact that foliage tended to be clumped at branch terminals and the tips of pendant shoots of the class 2 branches indicated that the foliage decrease was mainly from loss of older needles (Fig. 3).

Adventitious shoots occurred on the upper sides of branches on all branches samples in these 4 trees. For German Norway spruce, adventitious shoots have been reported as sometimes occurring on vigorous trees and on trees stressed by drought, but as being especially abundant on Waldsterben affected trees. In cases of serious decline, there may be more foliage on the adventitious shoots than on the pendant branches, giving the branches a very unusual appearance (Schutt and Cowling 1985). This pattern was not evident in the branches from the present study. Foliage weight of adventitious shoots was quite variable, with no pattern of class 2 trees having greater amounts. Some class 0 tree branches had very abundant adventitious shoots as well as vigorous pendant branch foliage (Fig. 4).

No casting of live shoots was observed in repeated visits to the site during 1986, except immediately following a windstorm. This appeared to be related to breakage from crown abrasion, rather than the active abscission.

Conclusions

When assessed by forest damage inventory methods used in Germany, most trees in the Massachusetts plantation fell into the "healthy" or "slight damage" classes, but 4% occurred in the "moderate damage" class or worse. These ground-level observations based on visual assessment of crown density were found to be consistent with direct measures of branch and foliage weight, indicating reduction in foliage amounts in the upper branches of the crowns, mainly on the older foliage of the pendant secondary branches. These observations are consistent with Waldsterben symptoms seen in German Norway spruce.

Three other symptoms sometimes seen in German spruce were not observed in the Massachusetts trees: 1. no yellowing of foliage was observed; 2. no dropping of live shoots from the crowns was observed except for one instance that was apparently related to normal wind damage; and 3. adventitious shoots were present, but their abundance appeared to be unrelated to a decreased total amount of foliage in declining branches.

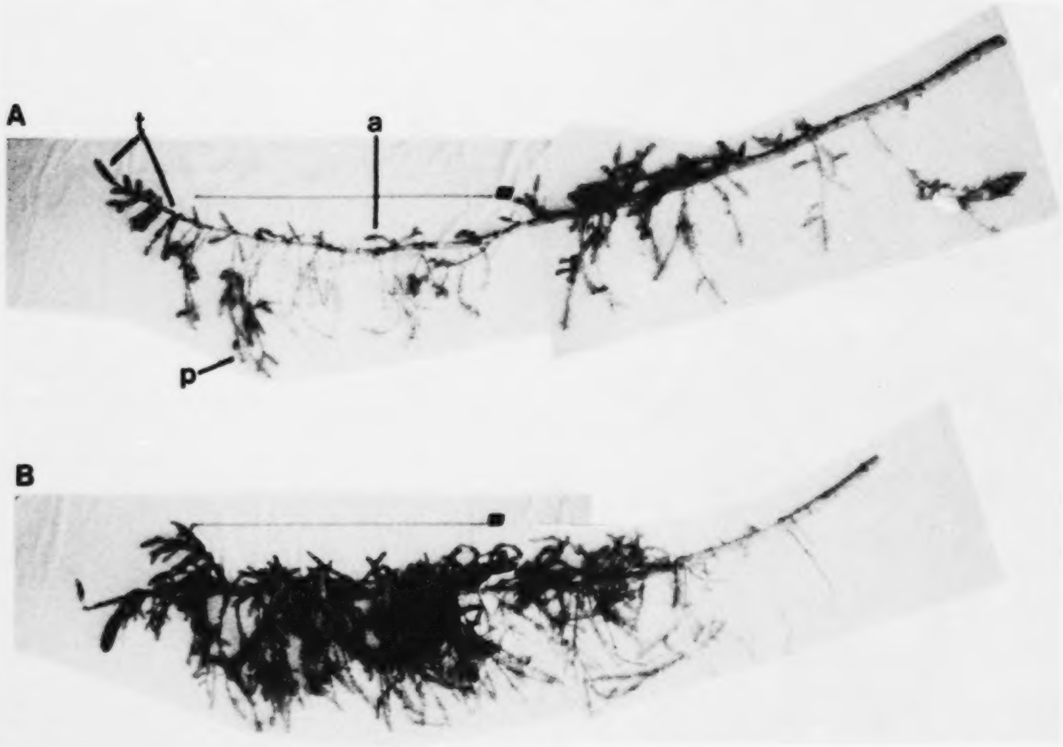


Figure 3.--Branches from upper portion crowns of (A) class 2 tree (moderate to serious damage) and (B) class 0 tree (healthy). Branch components are (p) pendant branches, (a)-adventitious shoots, and (t)-terminal shoot, including the main branch axis. Tape measure is 1 meter in length.

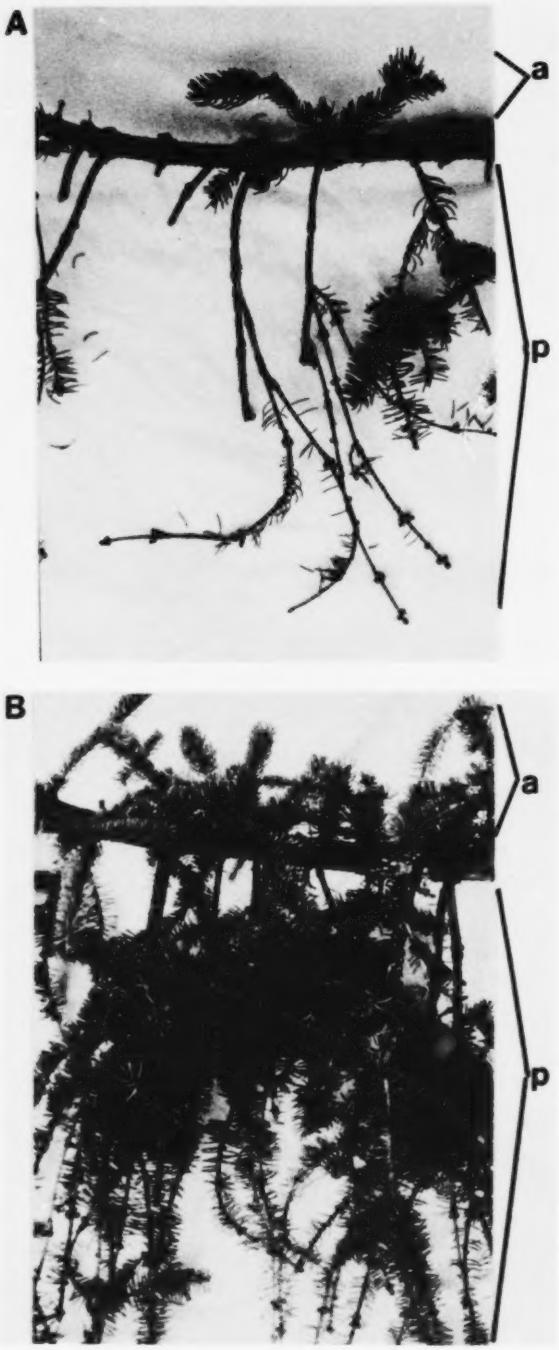


Figure 4.--Enlarged views of branches in Fig. 3. Foliage is denser on both pendant branches (p) and adventitious shoots (a) in the branch from the class 0 (healthy) tree (B) as compared to the class 2 (moderate to serious damage) tree branch (A).

Table 1.--Distribution of Norway spruce trees among five damage classes, for 76-year-old plantation on H.O. Cook State Forest, Colrain, Massachusetts. Damage classes are defined by density of foliage (see text for class definitions). Sample 1 consists of trees with crowns exposed for 1 year (at time of observation) by cutting of adjacent trees; sample 2 consists of trees with crowns exposed for 5 years. Table gives numbers of trees from each sample in each damage class, with percentage of sample in parentheses.

Damage class	Health	Sample 1 (150 trees)	Sample 2 (150 trees)	Combined (300 trees)
0	Healthy	110 (73)	108 (72)	218 (73)
1	Slight damage	38 (25)	32 (21)	70 (23)
2	Moderate to serious damage	2 (1)	6 (4)	8 (3)
3	Dying	0 (0)	1 (1)	1(<1)
4	Dead	0 (0)	3 (2)	3 (1)

Table 2.--Fresh weight of branches at different heights in the crowns of 2 trees rated as damage class 0 (healthy) and 2 trees rated as damage class 2 (moderate to serious damage) from Norway spruce plantation at H.O. Cook State Forest, Colrain, Massachusetts

Branch height: distance from top of tree (m)	Class 0 branches	Class 2 branches	Percent difference[a]	Sample size	T-test results[b]
	-------*kg/branch*--------				
2	1.59	.69	43	14	**
3	1.32	.83	63	7	*
4	2.53	1.03	41	14	**
6	2.79	2.42	87	13	ns
8	3.01	2.75	91	11	ns
10	2.82	2.87	102	9	ns
12	2.93	3.62	124	7	ns

[a] Class 2 weight as percent of class 0 weight.

[b] ** = significant at $p < .001$; * = significant at $p < .10$; ns = not significant.

These observations only document and describe the occurrence of symptoms, and cannot differentiate among the various possible causes for them. The basic symptoms are consistent with those linked at least in part to air pollution in Central Europe, but similar symptoms may be caused by disease, insects, drought, post-thinning decline, or other stress factors that cause a general decline in tree vigor. The greatest value of these observations lies in giving an initial assessment of tree vigor in this plantation, which can be compared with future assessments.

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Fichtensterben and Spruce Decline--A Diagnostic Comparison in Europe and North America

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Abstract

Morphological changes described on Norway spruce in southern Germany and linked to "spruce decline" were identified and classified in stands of Norway, red and white spruce in northeastern North America. All three spruce species in both countries showed similar patterns of defoliation, starting in the center of the crown and progressing distally. Defoliated portions of the crown are refoliated with secondary (epicormic) shoots. The formation of these secondary shoots correlated quantitatively with the degree of defoliation. Secondary shoots were found to be an unspecific response to stress.

Introduction

Starting in the late 70's, forest scientists in Europe and North America independently started recognizing major changes in forest ecosystems. The syndrome escalated within a few years into, what appears to be an international problem, affecting several genera and species in different ecotypes around the northern hemisphere. Monitoring work started in Germany in the early 80's and provides sufficient evidence to believe that most coniferous and deciduous species are affected. In North America quantitative changes in biomass, species composition and growth in coniferous forests have been documented in several regions throughout the northeast (Scott et al. 1984, Vogelmann et al 1985).

Norway spruce (*Picea abies* (L.) Karst.) is one of the most common and economically important coniferous species in Europe. Being also one of the species most affected by Waldsterben, a distinct group of symptoms and morphological changes related to the new syndrome was identified early and described in the European literature (Prinz 1982, Rehfuess 1983, Schütt et al. 1983, 1984, 1985, Ulrich and Pankrath 1983, Westman 1987).

In North America the attention has focused on red spruce (*Picea rubens* Sarg.); a major component of high elevation forest ecosystems exhibiting rapid decline over large areas in the Appalachian Mountains and the Adirondacks (Cowling and Linthurst 1981, Johnson and Siccama 1983, Friedland et al. 1984, Scott et al. 1984, Bruck 1984, Vogelmann et al. 1985).

Noting considerable discussion about possible similarities or differences of the syndrome in both continents, this study was initiated in 1985, to compare recent changes in forest ecosystems in Europe and eastern North America.

Norway spruce, introduced in extensive plantations in New England in the first half of this century, was used as a bioindicator to analyze similarities in the symptomatology between Germany an North America. Red spruce and white spruce (*Picea glauca* (Moench) Voss), growing mixed with or adjacent to selected Norway spruce, were evaluated, to compare the results to morphological changes on native conifers.

In this article 'spruce decline' will be used as a synonym for these recently identified morphological changes on different spruces in Europe and North America.

Methods

Site Selection

Starting in 1985 the sites for this study were selected, examining the stand for certain requirements. All sites in North America had Norway spruce present in mixture with--or next to--one or both of the native species; always growing under similar environmental conditions. The stands chosen, stocked according to current silvicultural knowledge (Fowells 1965, Dengler 1971, Mayer 1984) on favorable sites. Individual trees or stands damaged by obvious biotic or abiotic pathological conditions were excluded from the analyses. Interactions between natural stress factors, such as aspect, slope, soil moisture, precipitation or temperature and the causes of spruce decline are suggested in the literature (Schütt et al. 1983, 1984, Klein and Perkins 1987) and were considered in this study. Their impact on the appearance of the stands and the spruces within a stand was minimized through the selection of protected favorable sites.

The stands were not extremely affected by spruce decline, but exhibited a range of distinct symptoms and appearances of the syndrome. Interspecific and intraspecific competition within a stand imposes numerous stresses on individual spruces and greatly influence their morphological appearance. The potential impact of this factor in this study was reduced by evaluating only dominant and codominant (Kraft Klasse I and II) unsupressed trees.

Autochthonous Stands Were Selected in Southern Germany

All sites evaluated in New England and Bavaria had been treated silviculturally in the past. Those treatments, according to the current literature (Fowells 1965, Mayer 1984, Dengler 1971), must be considered favorable for the development of the individual and the stand, especially with respect to the resistance to natural and anthropogenic, biotic and abiotic stresses. Most sites had been previously cut and logged and were second or third growth forests, older than 50 years of age.

The criteria for the selection of the stands can be summarized as 'conditions promoting the resistance to predisposing, additive or synergistic, natural or anthropogenic stresses or factors with respect to the spruce decline syndrome'.

Seven stands were selected in 1986 in Bavaria, southern Germany (5 in the Bavarian Forest and 2 in the Alps). In Vermont, 2 stands were evaluated in 1985, 2 more in 1986 in central Maine and 1 site was in the Adirondacks in New York State in 1986.

Defoliation

Unusually increased defoliation was one of the first morphological features recognized and associated with spruce decline (Schütt et al. 1983, 1984, Vogelmann et al. 1985). Each spruce sampled in the course of this study was classified qualitatively for its defoliation pattern and quantitatively for the degree of defoliation. For the evaluation, both measurements may be clearly separated, according to their specific purpose. The degree of defoliation was grouped in five classes, as defined by Kennel and Zwirgelmaier (1985):

class I = 0 - 10 % defoliation

class II = 10 - 25 % defoliation

class III = 25 - 60 % defoliation

class IV = 60 - 100 % defoliation

class V = all recently dead individuals

(class V was not included in the assessment)

Only the loss of primary foliage was taken into account in this assessment; thus, a tree remained in defoliation class IV if it had lost more than 60% of its original foliage, but regenerated most of it through secondary shoot formation (epicormic shoots, stress shoots).

In order to obtain an accurate estimate, of all spruces were assessed from various sides, using binoculars. Sample sizes for each stand are shown by species in Table 1.

Branch Analysis

Preliminary analyses indicated the necessity of closer evaluation of different morphological features in the upper crown (Liedeker 1986). For each stand and for each species within a stand a representative sample of trees was selected from each defoliation class. Primary branches, representative for the condition of the individual were selected from the upper crown. It was assumed that those higher branches were still in the vigorous portions of the crown and thus were less influenced by senescence than lower ones; and that these branches, showing defoliation earlier than branches from the lower crown (Schütt et al. 1983, 1984), would also exhibit other symptoms earlier than other parts of the crown. In America, branches were selected and cut from standing trees, while in southern Germany branches were removed after felling. Sample sizes for the branch analysis (Table 2) vary widely with defoliation distributions and accessibility of the crown.

Stress Shoot Analysis

It has been documented that different spruce species have the capacity to regenerate lost foliage through the formation of epicormic shoots (Krampol 1983, Krug and Schill 1984, Schütt et al. 1983, Rehfuess et al. 1984, Johnson et al. 1986). 'Stress Shoots' was selected as a common name for such epicormic shoots, indicating their initiation through some stress. The terms 'adventitious shoots', 'Nottriebe' and 'Regenerationstriebe' are also used frequently in the literature.

Stress shoots originate from dormant buds around older nodes (Krug and Schill 1984). Schütt (1983) and Rehfuess and Rodenkirchen (1984) suggested that epicormic shoots are a response of Norway spruce to defoliation related to Fichtensterben. Epicormic shoots on other conifers are known to be a distinct response to stress (Consens 1952).

In order to quantitatively classify stress shoots the following definition was introduced for their identification. All shoots of any one internode (or the preceding node) being four or more years younger than the oldest shoot on that node or internode were classified as secondary and stress induced, and are being called stress shoots.

All internodes newly formed in the current growing season were counted, irregardless of their position on the branch, as a measure for foliage regeneration of the entire branch. To evaluate the importance and role of epicormic shoots in the process of foliage regeneration, all new internodes formed in the current season on previously identified stress shoots were summed.

In addition, the stress shoot phenomenon was described in detail for each species on all branches evaluated.

Transformation of Data and Statistical Analysis

BMDP (Dixon 1985) and SPSS^{x} (SPSS 1983) software packages were used for statistical analysis. Defoliation distributions for different species in the same stand in North America were compared using a Pearson chi-square test (Dixon 1985). The level of significance for the null hypothesis of homogeneity was set at 5%. Cramer's v test (Afifi and Azen 1972, Dixon 1985) was employed as a descriptive measure of the association between species and defoliation class.

Data collected in the branch survey indicated in preliminary evaluations an immense inter- and intraspecific variability. The following transformation was utilized on the raw data:

Variable I

$$\begin{array}{c}\text{Relative amount of}\\ \text{stress shoots on}\\ \text{total new foliage}\\ \text{(Table 3)}\end{array} = \frac{\begin{array}{c}\text{Total number of new}\\ \text{shoots on stress shoots}\\ \text{(Table 3)}\end{array}}{\begin{array}{c}\text{Total number of new}\\ \text{shoots (Table 3)}\end{array}} \times 100$$

Table 1.--Sample sizes for the ground survey by stand, species and dominance class (Kraft Klasse) (D:dominant, CD: codominant)

Site	*Picea* abies		*Picea* rubens		*Picea* glauca		Sub-total		Total
	D	CD	D	CD	D	CD	D	CD	
Bangor/Maine	38	57	--	--	40	55	78	112	190
Brighton/Maine	45	59	36	35	37	71	118	165	283
Newcomb/New York State	43	57	15	21	29	23	87	101	188
Granville/Vermont	94	32	31	50	--	--	125	82	207
Callahan/Camels Hump/Vermont	50	52	53	49	--	--	103	101	204
Bachhange/Roding/Bav. For.	37	62	--	--	--	--	37	62	99
Ried/Kotzting/Bavarian Forest	58	79	--	--	--	--	58	79	137
Heidbirket/Roding/Bav. Forest	44	76	--	--	--	--	44	76	120
Kirchriegel/Kotzting/Bav. For.	62	74	--	--	--	--	62	74	136
Schwarzriegel/Kotzt./Bav. For.	78	42	--	--	--	--	78	42	120
Kastengraben/Fussen/Alps	64	26	--	--	--	--	64	26	90
Alpele/Fussen/Alps	59	61	--	--	--	--	59	61	120
Subtotal	672	677	135	155	106	149	913	981	1,894
Total	1,349		290		255		1,894		

Table 2.--Sample sizes for the branch analysis by stand and species (Pa:*Picea abies*, Pr:*Picea rubens*, Pg:*Picea glauca*, Class = Defoliation Class)

Site	Class 1			Class 2			Class 3			Class 4			Subtotal			Total
	Pa	Pr	Pg	Pa	Pr	Pg	Pa	Pr	Pg	Pa	Pr	Pg	Pa	Pr	Pg	
Bangor/Maine	16	--	16	13	--	14	19	--	16	15	--	16	63	--	62	125
Brigthon/Maine	11	12	11	11	10	11	13	14	12	16	11	10	51	47	44	142
Newcomb/New York St.	7	9	11	7	3	9	7	3	6	8	12	9	29	27	35	91
Granville/Vermont	10	8	--	8	10	--	9	8	--	8	6	--	35	32	--	67
Callahan/Vermont	10	10	--	10	10	--	10	10	--	10	11	--	40	41	--	81
Bachhange/Bav.For.	9	--	--	12	--	--	12	--	--	9	--	--	42	--	--	42
Ried/Bav.For.	10	--	--	10	--	--	10	--	--	10	--	--	40	--	--	40
Heidbirket/Bav.For.	12	--	--	11	--	--	16	--	--	3	--	--	42	--	--	42
Kirchriegel/Bav.For.	10	--	--	10	--	--	11	--	--	8	--	--	39	--	--	39
Schwarzriegel/Bav.F.	15	--	--	15	--	--	15	--	--	15	--	--	60	--	--	60
Kastengraben/Alps	9	--	--	--	--	--	--	--	--	9	--	--	18	--	--	18
Alpele/Fussen/Alps	10	--	--	11	--	--	10	--	--	13	--	--	44	--	--	44
Subtotal	129	39	38	118	33	34	132	35	34	124	40	35	503	147	141	791
Total	206			185			201			199			791			

Variable 1 (herein: *STRESS-REGEN*) is an expression of the amount of newly formed foliage on stress shoots as a percentage of the total newly developed foliage on the same branch in the current vegetation period. This new variable provides a quantitative measure for the portion of foliage regenerated by stress shoots.

The transformation of the raw data reduces the variability within and between all three species and facilitates the comparisons of differently sized branches from various locations within the crown. The sites in America, like the sites in Germany were combined in this analysis after analysis of variance (Dixon 1985) showed no significant interaction between site and defoliation class with respect to "STRESS-REGEN".

Boxplot diagrams (McGill et al. 1978, Eggenberger 1985) were used to graph the data. This technique is explained in detail in preceding reports (Liedeker et al. 1986, 1988).

The distribution of 'STRESS-REGEN' over different defoliation classes was tested for equality using analysis of variance. The use of this procedure is justified by the large sample sizes and more normal distributions, resulting from pooling the sites in America and Germany. This test is more powerful than the nonparametric Kruskal-Wallis test used in preceding reports to test the sites separately. The level of significance for the null hypothesis of independence was set at 5%.

Spearman's rank correlation test (Lehmann 1975, SPSSX 1983) was used to provide a measure for the association between 'STRESS-REGEN' and defoliation class.

Results

Defoliation

A characteristic defoliation pattern, progressing distally from the center of the crown (Knabe 1981, Schütt et al. 1983, 1984) was identified in all stands in southern Germany. This course of defoliation on Norway spruce results in most instances in a distinct "window" or "hole" in the upper crown.

Norway, red and white spruce in northeastern North America showed identical patterns of foliage loss, in all cases starting in the inner crown approximately one third crown length from the top and progressing more or less rapidly outward and downward.

Norway and white spruce in northeastern North America show in these stages a distinct "hole" or "window" in the upper crown. On several heavily damaged individuals in Germany and North America it was observed that the upper crown is only affected in the terminal stages of the syndrome.

The defoliation distributions for the German sites (Figure 1) clearly demonstrate that neither heavily damaged nor absolutely healthy stands were selected and that a broad spectrum of different stages and appearances with respect to the syndrome was covered.

Separate analyses for each stand in America detected no significant differences between the degree of defoliation for different species. Cramer's v test indicated only a weak association between defoliation class and species. All American sites were combined for this report and the defoliation distributions for the three species are shown in Figure 2.

Statistical tests for each species and each stand indicated no significant differences between the degree of defoliation in both dominance classes, which parallels findings by Maier (1984) in southern Germany.

Stress Shoot Analysis

Extensive stress shoot formation was observed on all three species in North America and Norway spruce in Germany. No qualitative or quantitative differences were found between Norway spruce in southern Germany and in the northeastern United States. The formation of stress shoots generally starts in the immediate vicinity of older nodes and can continue for several years, resulting in thick cluster of various generations of epicormic shoots (Figure 3). Internodes are only affected in later stages. Nodes surrounded by these epicormic shoots seem to show temporarily increased vigor over nodes that did not produce such shoots. This strength, indicated by an increased formation of new growth on stress shoots **and** primary side branches, gradually decreases.

All three species tend to replace lost foliage with stress shoots. The inner crown is partly restored and appears to be dense and green again. The regeneration of foliage through stress shoots progresses distally from the base of a given branch. It usually does not reach outermost internodes of the twigs, which may subsequently defoliate, desiccate and brown.

When the age structure of stress shoots within clusters was assessed it was noticed that the bulk of the foliated stress shoots had between 5 and 10 nodes, underlining the temporary character of this foliage regeneration. Evaluating branches from recently dead trees, still showing dense clusters of defoliated epicormic shoots emphasized this finding. No cause for the decline in vigor of stress shoots over time was apparent. Different age classes, with the exception of very young trees, seem to be equally prone to the initiation of stress shoot formation. Red spruce in America showed a far greater capacity for regeneration of lost foliage than the other two species. In one instance a maximum of 96 individual stress shoots was identified in the vicinity of a single node on an extremely damaged red spruce branch, while 40 or more stress shoots were found frequently along the same internode.

The identification of stress shoots even from the ground presented no problem on all three species, although it was easiest on even shaped Norway spruces (comb-variety).

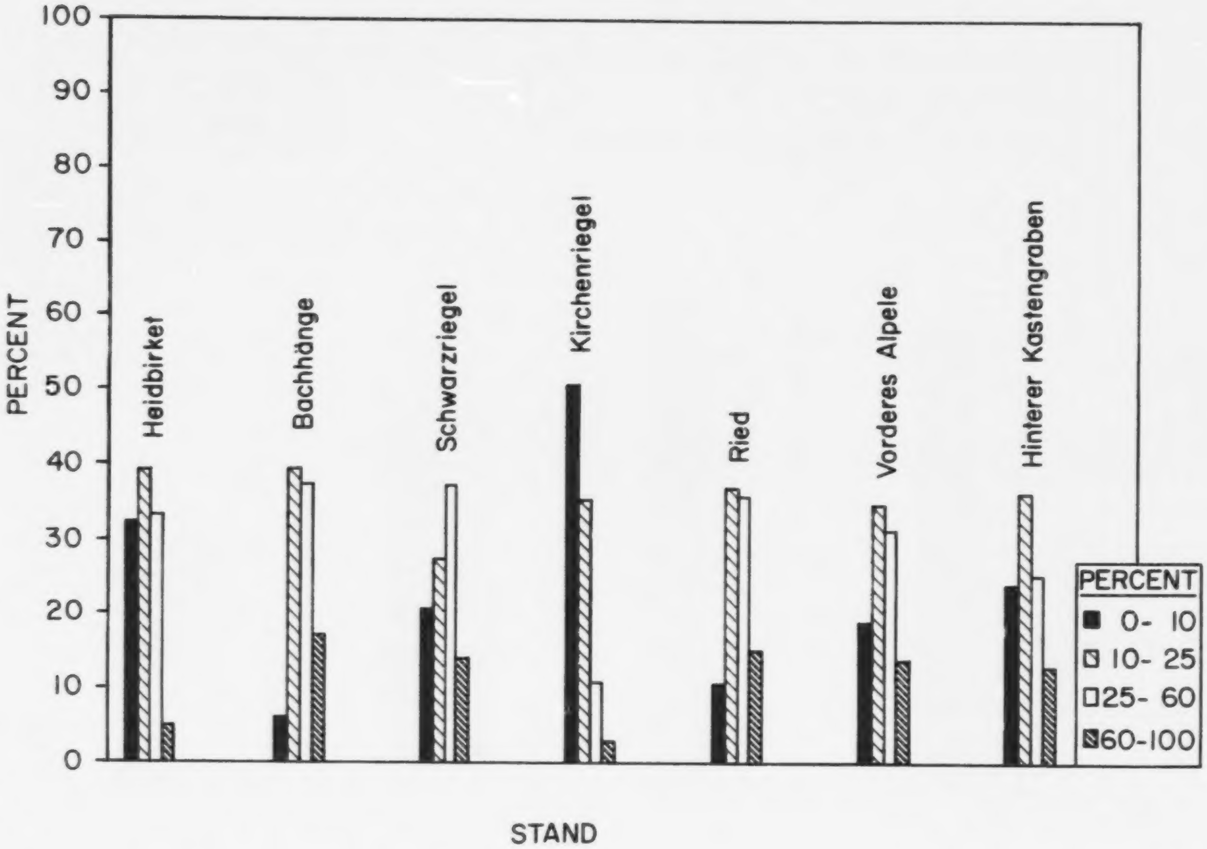

Figure 1.--Defoliation distrbutions for the Norway spruce sites selected in southern Germany.

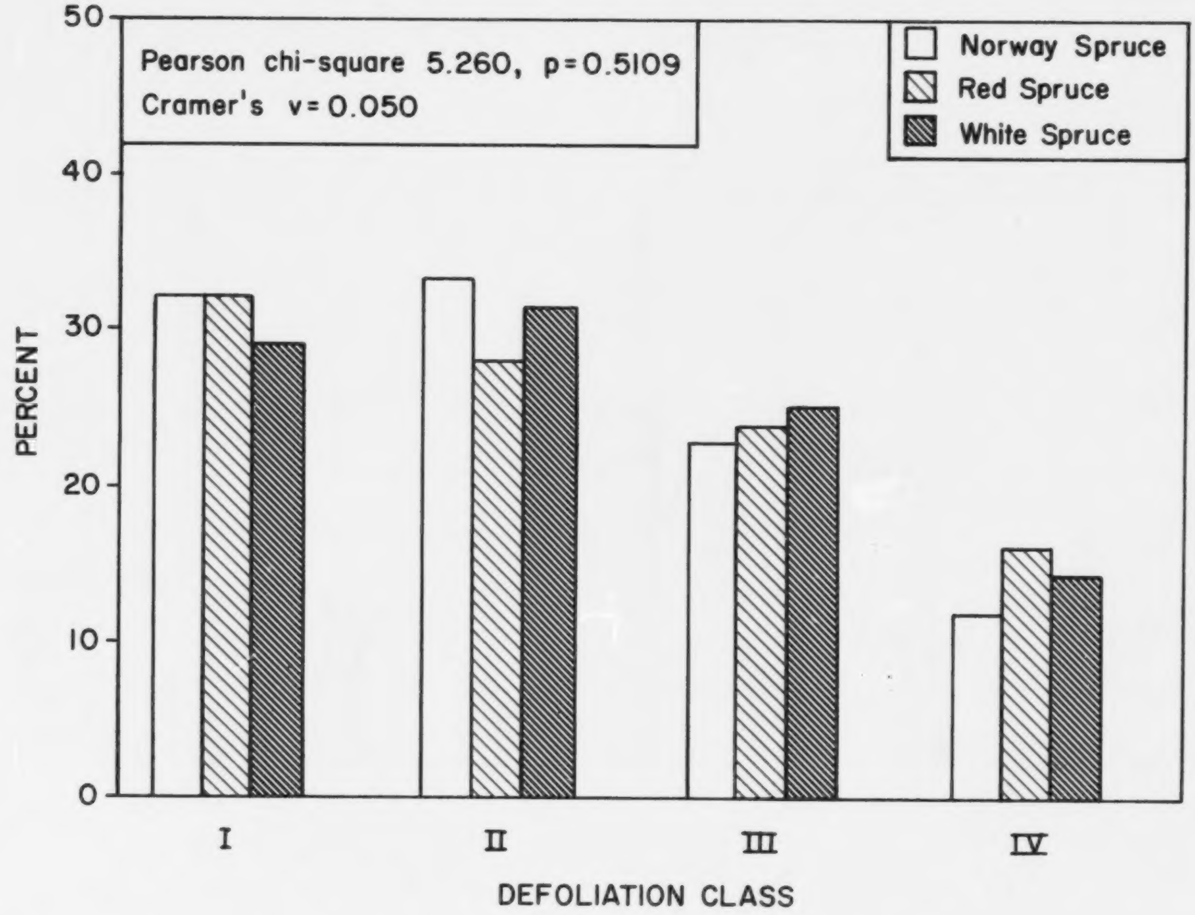

Figure 2.--Defoliation distributions for all three species in northeastern North America.

Table 3.--Descriptive statistics for the transformed variable STRESS-REGEN and its raw data, pooled for the sites in Germany and North America

Species		n	Mean	Median	Std.Dev.	Min.	Max.
Total number of new shoots	*P.abies* (Eur.)	285	209.87	186	112.07	39	993
	P.abies (Amer.)	218	242.19	205	134.90	43	794
	P.rubens (Amer.)	147	381.11	341	234.16	0	1688
	P.glauca (Amer.)	141	312.75	287	146.86	67	816
Total number of new shoots on stress shoots	*P.abies* (Eur.)	285	70.92	53	75.15	0	847
	P.abies (Amer.)	218	93.27	69	87.27	0	633
	P.rubens (Amer.)	147	146.18	112	146.66	0	1208
	P.glauca (Amer.)	141	101.91	91	71.01	10	463
STRESS-REGEN (Rel. amt. of str. shts. on tot. new fol.)	*P.abies* (Eur.)	285	35.33	31.58	24.37	0.00	96.05
	P.abies (Amer.)	218	39.31	39.14	26.00	0.00	98.75
	P.rubens (Amer.)	146	38.84	36.75	25.17	0.60	97.07
	P.glauca (Amer.)	141	35.79	33.09	22.88	3.91	84.62

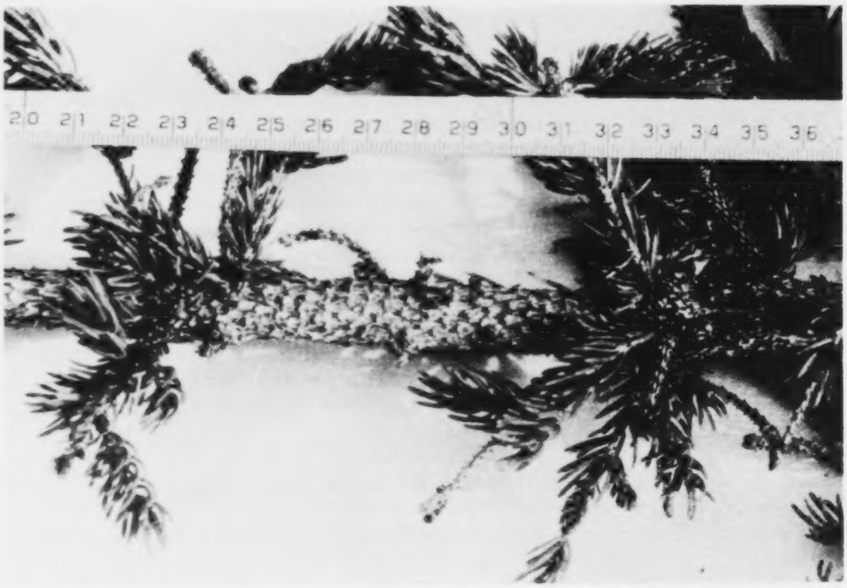

Figure 3.--Example of a red spruce branch showing clusters of stress shoots around older nodes.

Table 3 displays the descriptive statistics for STRESS-REGEN and the raw data. The maxima for STRESS-REGEN impressively show that stress shoots can indeed regenerate over 90% of the foliage of severely damaged individuals. The relationship between STRESS-REGEN and defoliation class is shown in Figure 3 (note: each boxplot represents a distribution of samples taken for that defoliation class). This highly significant association between stress shoot formation and defoliation class suggests a common causal base for both pathological features.

Discussion

Defining several restrictive criteria for site selection limits the widespread application of this study to other sites. The symptoms observed in such stands, on the other hand, are more likely to be the result of pathological events rather than a reflection of natural environmental site conditions and stand dynamics.

It is the author's opinion, that the use of restrictive criteria in site selection was justified, especially since a description of the extent of changes for the whole stand was not attempted. The sole objective of this study was the identification of, and the correlation between such changes, independent of the overall condition of the stand.

The descriptive analysis of the course of defoliation of all three species in Europe and North America demonstrated clearly that Norway, red and white spruce exhibit identical defoliation patterns under similar conditions.

No evidence was found in the sites selected to support the thesis that red spruce defoliates from the outside of the crown towards the center (Siccama et al. 1982, Johnson and Siccama 1983, Friedland et al. 1984, Weiss et al. 1985). Frost or wind damage, known abiotic stresses can certainly lead to apical die back and initiate the formation of secondary foliage on all spruce species in Germany as well as in North America. It is distinctly different from the changes described in this study, even though it may have additive or synergistic effects on spruce decline. The combination of known and unknown stresses is highly probable in high elevation forest systems, naturally confronted with numerous biotic and/or abiotic stresses. The recognition of the course of defoliation in highly stressed ecosystems is aggravated by the constant formation of stress shoots.

This study suggests that it is not possible to properly assess the progress of defoliation on an individual spruce (especially red spruce) showing dry branch tips (Friedland et al. 1984, Evans 1986) and almost only secondary foliage (frequently observed in high elevation sites). It may have completely shed its primary foliage, distally from the center of the crown and subsequently regenerated the inner crown with stress shoots, or it may have suffered repeated apical die back and refoliated the crown with stress shoots leaving the dead tips bare of foliage. Both chains of events leading to a similar appearance of damaged red spruce were observed in this study and are equally valid. A qualitative and quantitative evaluation of high elevation sites on the exposed western side of Camels Hump, Vermont suggests, that it is not possible to accurately determine any chain of events leading to these terminal symptoms of decline.

Similar scenarios were observed in the course of this study under similar site conditions in the German Alps on Norway spruce. The selection of low elevation sites, with little or no apical die back (due to winter damage), facilitated the clear identification of these morphological changes.

Figure 4 shows the highly significant correlation between defoliation and the formation of secondary foliage. This study cannot provide evidence for a causal relationship between these two features. It is the authors opinion, that stress shoot formation is likely to be a reaction to extensive foliage loss. It is known that numerous natural and anthropogenic stresses can produce intensive formation of epicormic branches. This symptom therefore has to valued as a rather unspecific response to stressing changes in environmental conditions.

Stress shoots were found to provide easily over 50% of the total foliage and up to 98.75% (Table 3) of the newly formed foliage in the sites researched. Red spruce indicated its special capabilities for primary and secondary shoot formation by generating 1688 new shoots in one vegetation season on a branch of 2.54 meters in length (Table 3). Of these, 1208 were situated on existing stress shoots or formed a new stress shoot. The other two species did not come close to such numbers (Table 3). These results, found in stands protected from severe environmental conditions, underline again the importance of stress shoot identification for any type of quantitative analysis.

Quantitative analysis of severely damaged red spruces on the western slope of Camels Hump revealed considerably higher numbers of stress shoots contributing an even higher portion to the living foliage and foliage regeneration. An example of such an individual showing almost only secondary foliage in thick clusters in the inner crown in Figure 5 (note the dead branch tips, not forming secondary shoots).

Since it is not yet known if stress shoots are morphologically or physiologically different from primary shoots, major emphasis must be placed on the identification of secondary foliage for inventory work or causal research. The importance of foliage regeneration for partly defoliated spruces is clearly demonstrated in this study.

Independent of the causes of recent changes in forest ecosystems in western Europe and northeastern North America, this study established similarities in the reaction of different species in both continents.

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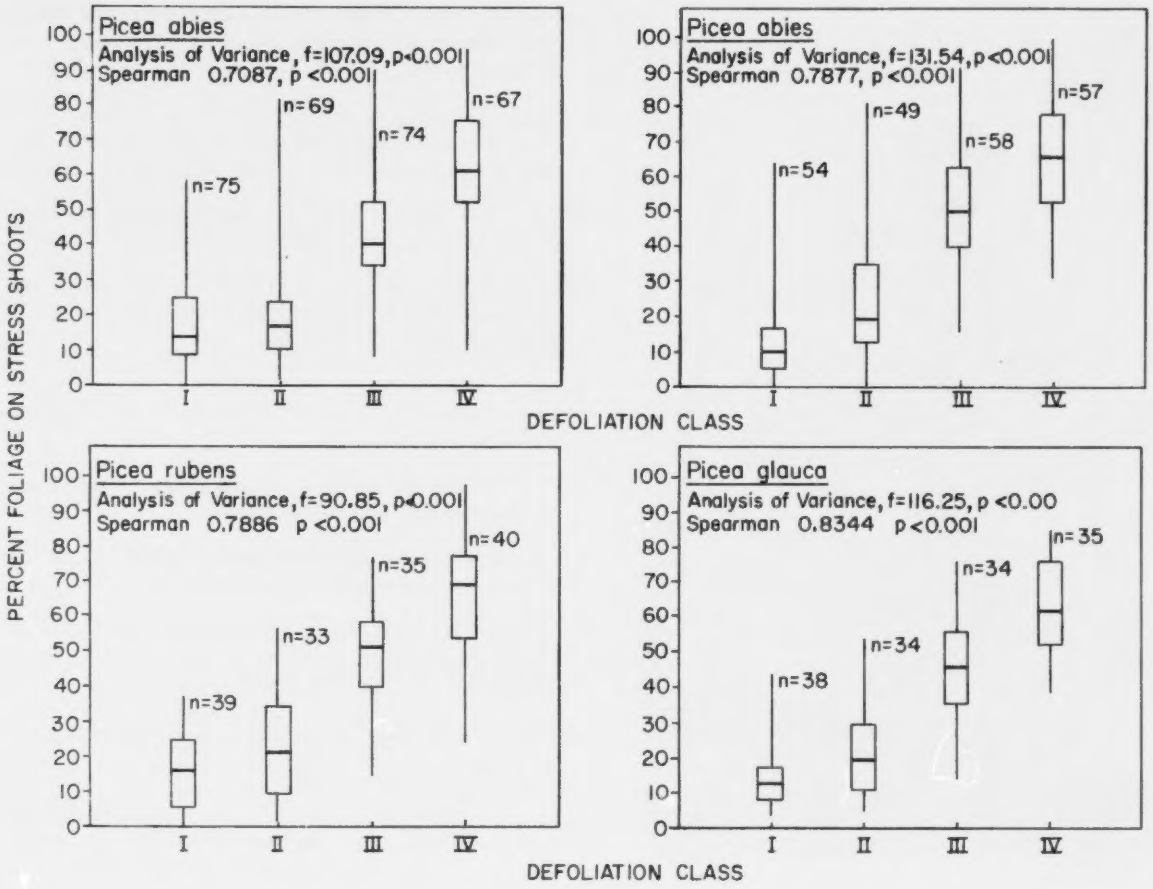

Figure 4.--Boxplot diagrams for STRESS-REGEN separately for Norway spruce in Germany and America, red spruce and white spruce.

Quednau, Th. Liedeker, Jeff Tricou, T.D. Perkins, T.D. Scherbatskoy, H.Whitney-McIver, the district foresters Perras, Scheffelmann, Bartl and their crews in Germany, Dr. W. Livingston, Dr. R. Jagels, Scott Paper Company, Downeast Timberlands, the Adirondack Ecological Center and the Green Mountain National Forest for the help in the field and during the analysis. The study was financially supported by the "Gesellschaft der Freunde und Förderer der Univerisitat München", the Bundesministerium für Forschung und Technik (West Germany), the Vermont Agricultural Experiment Station, the R.K. Mellon Foundation and the Jackson Hole Preservation Foundation.

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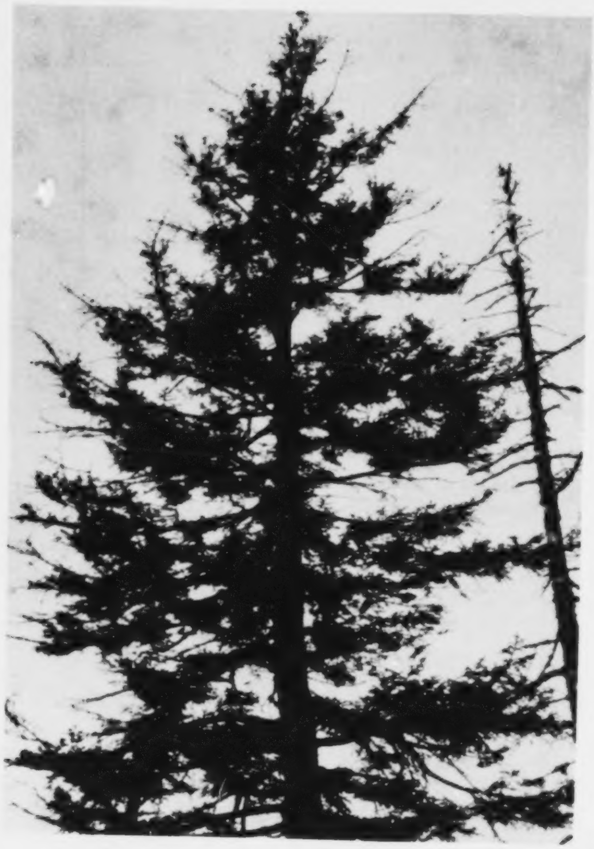

Figure 5.--Severely damaged red spruce bare of primary foliage, showing dense clusters of secondary shoots in the center, and dry branch tips at the periphery of its crown. Photo courtesy of T.D. Perkins, Botany Department, University of Vermont.

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A Preliminary Report on Observations of the Health of Norway Spruce in Three Northeastern States

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Abstract

Fifteen trees within each of seven Norway spruce plantations were evaluated during 1987 with two plantations each in New Hampshire and New York and three in Pennsylvania. Foliage discoloration and defoliation ratings were made using the American and West German systems. Both systems indicate that trees are experiencing slight off-coloration and defoliation of &10%. The predominant symptom found on trees in all plantations was yellowing of the upper needle surface; this symptom was not usually in evidence via ground observation and was observed following removal of two branches from the top and mid-point of the live crown. Older needles were most symptomatic. The symptom was most severe in plantations located in the Tug Hill area of New York. The presence of twelve major and trace nutrient elements were determined. The Mg-content of most of the 2nd to 6th needle year complements, especially for the symptomatic trees, was 0.02% to 0.05%. Mg nutrient content of soil for the symptomatic trees was likewise deficient.

Introduction

The forest decline situaton in Western Europe and in particular within the Black Forest of Germany has come to the forefront of concern due to its potential causes being due to ozone, acidic rain, and resulting nutrient deficiencies. In Germany, the principal species studied has been Norway spruce, *Picea abies* (L) Karst., since this species is severely affected and comprises 40 percent of the German forest stands. However, in major studies in the United States this species has not been studied in favor of studies on high altitude red spruce (*P. rubens*, Sarg.) stands where a decline situation has been noted. Therefore, until our preliminary observations on Norway spruce in Pennsylvania were made, no studies had taken place on a "common" species between the U.S. and German forest situations. A major objective of our studies is to serve in linking our two countries' respective efforts via continuing observations of symptom progression in Norway spruce.

Specific objectives include 1) observation of Norway spruce in Pennsylvania and other northeastern states to determine if a symptom complex similar to that observed in European forests in occurring, and 2) determination of an hypothesized causal complex of ozone exposure followed by acidic precipitation and its resultant role in foliar nutrient/soil nutrient deficiencies through foliar and soil leaching.

During the past ten to twelve years a decline in several forest tree species has been reported in Germany and several other countries in central Europe (Schutt and Cowling 1985). Since the late 1970s, damage has been specifically noted on Norway spruce. Schroter (as cited in Blank 1985) observed plots in severely affected areas of Baden-Wurttemberg and found a rapid increase in damage to Norway spruce from 6 percent in 1981 to 94 percent in 1984. Symptoms on Norway spruce in Germany have been described and pictorially presented in a publication of the Allgemeine Forst Zeitschrift (Anon. 1984). Thinning of crowns, severe branch droop, loss of older needles, yellowish-gray appearance of foliage, top dieback, reduced radial increment growth, and tree death have been the most prominent symptoms reported.

The most widespread symptom of decline in Norway spruce has been a loss of foliage and a thinning of the crown. Several patterns of foliage loss have been described by Schroter and Aldinger (1985). As cited by Ciesla and Hildebrandt (1986), the "Larchen-Typ" (Larch Type) consists of a more or less overall thin appearance to the crown with greatest foliage loss occurring in the lower crown. In the "Fenster-Typ" (Window Type), foliage loss is concentrated on the inner portions of the crown, giving the tree a tufted appearance. Schütt et al. (1983, 1984) also reported that needle loss progresses from the inside of the crown to its periphery.

Foliage loss may be accompanied by branch dieback, which is often concentrated just below the tip of the crown, and has been referred to as sub-top dieback. Top dieback, which is commonly associated with repeated outbreaks of conifer defoliating insects in North America, is also part of the decline syndrome on spruce in Europe (Ciesla and Hildebrandt 1986). Johnson et al. (1983) found that spruce *(P. rubens)* dieback occurs from outside towards the center of the crown.

Some spruce trees that naturally have an almost vertical habit of branching show a so-called silver tinsel symptom. When needle loss is severe, the "hanging" bare branches resemble those of a Christmas tree decorated with silver tinsel (Schütt and Cowling 1985).

Another very commonly reported symptom has been chlorosis of the older foliage. This symptom has been seen in many spruce stands at mid and upper elevations throughout West Germany (Ciesla and Hildebrandt 1986). The symptom initiates with the appearance of tiny yellow-whitish spots on the upper surface of the needle and begins between 1 and 3 years after needle emergency. The intensity of the symptom increases with increasing

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needle age. In later stages these dots merge along the edges of the needle until they form large necrotic areas several millimeters in diameter (Land and Holdenrieder 1985, cited by Liedeker). Ciesla and Hildebrandt (1986) also reported that the yellow discoloration tends to be most conspicuous on the upper needle surface and is generally confined to the older needles. In 1985, the most typical pattern of chlorosis was a yellowing of needles three years old and older. A red-brown discoloration of spruce foliage is also reported but does not appear to be as widespread as is the chlorosis symptom. This type of discoloration occurs on the current years growth, similar to that reported for red spruce in the Northeastern United States (Friedland et al. 1984).

Huettl (1984) reported that the comparisons of the nutritional status via foliar analysis findings of Norway spruce and Silver fir stands in southwest Germany indicate generally different nutrition problems depending among other factors of the site and stand conditions, degree of decline and specific geological parent material. Reduced or deficient nutrient supply has been found via needle analysis for Mg, Ca, K, and in some cases for Zn.

Huettl and Wisniewski (1986, in press) have reported successful efforts in using several combinations of fertilizers in alleviating the foliar symptoms on young spruce. Their studies were initiated on the premise of injury due to photochemical oxidants and SO_2 followed by enhanced leaching of nutrients from foliage by acidic precipitation (Prinz et al. 1982; Fink 1983; Roelfs et al. 1985). Major liming and fertilization studies have been initiated in Germany in relation to alleviating "Waldsterben."

Current Observations

During the Fall of 1985 and early Winter of 1986 an informal survey of Norway spruce was conducted on the campus of The Pennsylvania State University and in Southcentral Pennsylvania (Skelly 1986). German scientists (Dr. Bernd Prinz, Dr. Reinhard Huettl, Ms. Bieta Mehni, Dr. Sigfried Fink, and Dr. Heinz Zoettl) have visited the Penn State campus and have noted similarities between their personal observations on Norway spruce in the Black Forest and those symptoms found on campus trees.

Symptoms on all examined trees closely resemble those photographically presented by the Allgemeine Forst Zeitschrift publication (Anon. 1984). Advanced symptoms on a small planting of Norway spruce also existed at a site near Embreeville, Pennsylvania. Needle loss, needle discoloration, droop of branches, thin crowns with main stems visible for the entire height, top dieback, tufting, and over abundant and "misplaced" cone production were noted.

Preliminary observational surveys have been conducted in Center, Cambria, Chester, Franklin, Westmoreland and Pike counties in Pennsylvania. In all of the Pennsylvania counties visited, Norway spruce exhibited many symptoms of stress similar to those reported by our German colleagues and as observed during a personal tour in the Black Forest of W. Germany by J.M. Skelly. In most instances, the symptoms included premature defoliation leading to the well-known tinsel effect, bronzing or browning of older needles, thinness of crowns to the point of trunk visibility, and evidence of cytospora canker *(Cytospora* spp.) on small and larger branches; spruce spider mite *(Oligonychus ununguis,* Jacobi) injury was also a predominant symptom frequently observed.

Several northeastern states have been visited in a preliminary sense for a "quick" overview of possible "Waldsterben" like symptoms on Norway spruce.

Maine: During the summer of 1986, three sites were examined in the Bangor-Penobscot-Howland area. In addition observations were made on landscape Norway spruce between plantation stops. The symptoms of the nonspecific stress syndrome were present but not to the degree observed elsewhere (i.e., Pennsylvania). Of the three plantation sites visited only one had any evidence of symptoms. The site north of Howland, Maine, had numerous trees with notable resin flow at the stem bases with subsequent probing indicating cambial death there and along exposed roots. Suspicion of *Armillaria* spp. incited shoe string root rot was not confirmed. The other two Maine plantations were asymptomatic for any decline symptoms.

Ohio: A small planting of Norway spruce was examined in a cemetery at the periphery of Delaware, Ohio. Typical symptoms of the nonspecific stress syndrome were present as was the best example of the three Norway spruce phenotypes present at one site, i.e., the comb, brush, and plate phenotypic expressions of branching habit.

Observations made during these surveys suggested that Norway spruce exhibits several symptom complexes in response to varying environmental stresses. Many of the specimens observed early in this project most likely suffered from abuse through soil compaction, improper fertilization, drought, herbicide application for turf-weed control, road salt application and subsequent drift, and numerous other stress inducing agents. In most instances of crown thinning, limb death *(Cytospora* spp.), tinseling, and needle symptoms, conditions of the symptomatic tree's growth habitat were such that great difficulty would arise if attempts were made to ascribe specific single causes of decline. In more cursory examinations of the general health of Norway spruce throughout the Northeast, symptoms of general malaise appear evident but in each instance, habitat and related obvious stress agents could have been indicted. Thus in 1987, investigations were initiated within plantations of Norway spruce planted in more remote, undisturbed areas. Preliminary results of observations of foliar symptoms and magnesium content of foliage follow.

Plantations were selected with the assistance of forestry personnel within the respective states and counties. No evaluations of the plantations had taken place prior to our visits and subsequent plot selections. All visited plantations were selected for plot establishment with the exception of one stand in New York in which trees were too tall to allow sample collections (Table 1).

Within each plantation fifteen dominant or co-dominant trees were selected for study. No edge trees were sampled except for 3 trees in Plantation 1. Tree heights, heights to live crown, dbh, and crown class were recorded. Numerous measures of overall tree health were recorded using a modified survey system developed by the USDA-Forest Service (Millers and Miller-Weeks 1986). Trees were evaluated for degree of defoliation and discoloration using the West German and American systems (Table 2).

Trees were climbed and two branches were removed at the main stem from the top and mid-live-crown portion of each tree. Branches were samples from the SW side of each tree when all branches of the tree were "equally" exposed to sunlight; branches with direct exposure were sampled when possible on all other trees. Branches were removed to the laboratory for needle, twig, and branch symptoms and foliar nutrient analysis. Symptom analysis will be reported elsewhere as will a more complete analysis or foliar nutrient findings. Preliminary Mg data are presented in Table 3.

Soil was sampled at four points under each of the fifteen sample trees at two depths (0-10 and 20-30 cm) and composited on an individual tree basis by depth. Data for Mg content has been presented in Table 4.

Preliminary analysis of our observations indicate that the yellowing symptom of the older foliage of Norway spruce as noted in European forests is likewise evident throughout plantation grown Norway spruce in Northeastern United States. Apparent health of sampled trees varied within plantations and between plantations at differing localities. Trees appeared to be in poorest health in Plot 3 (Laurel Hill Plantation, Somerset CO., PA) and Plot 4 (G. Higby Plantation, Lewis Co., NY). Yellowing of foliage was very evident via ground observation of trees within these two plantations. Slight foliar yellowing was in evidence in the other plantations and was very evident when branches were examined via hand-held observation following their removal. Yellowing was more intense on older needles.

Laboratory observations have yielded relatively few known insect of foliar biotic pathogens in evidence on affected foliage. The spruce spider mite, eastern spruce gall adelgid *(Adelges abietis* L.)., needle cast *(Rhizosphaera kalkhofii Bubak)* and the branch canker fungus *(Cytospora* spp.) have been occassionally present but at this point cannot be held accountable for observed symptoms.

Obvious Mg deficiency exists in most of the plots (2-7) on both a foliar and soil content and availability basis. No attempt has yet been made to evaluate the interaction of foliar symptom expression and observed Mg contents, nor has analysis of the eleven other tested elements been completed. Investigations are continuing.

Acknowledgment

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Table 1.--Location of seven Norway spruce plantations observed in three northeastern states in the summer of 1987.

Plantation	Owner	County	Location
1	W. Clark	Centre Co.	State College, PA
2	Pa. Bureau For.	Clearfield Co.	Elliott State Park
3	Pa. Bureau For.	Somerset Co.	Laurel Hill Forest
4	G. Higby	Lewis Co.	Constableville, NY
5	A. Woyciejes	Lewis Co.	Turin, NY
6	N.H. For. Comm.	Hillsborough Co.	Hillsborough, NH
7	N.H. For. Comm.	Hillsborough Co.	Deering, NH

Table 2.--Mean foliar rating of discoloration and crown defoliation for fifteen Norway spruce located in seven plantations across three northeastern states using the American and West German rating systems

	German Rate System[2]			German Rate System[3]			American Rate System			American Rate System		
	Upper Crown			Lower Crown			Upper Crown			Lower Crown		
Plantation[1]	Discol	Color[4]	Defol	Discol	Color	Defol	Discol	Color	Defol	Discol	Color	Defol
1	1.4	0.9	1.8	1.9	0.9	2.4	1.4	0.9	2.5	1.9	0.9	2.9
2	1.1	1	1.8	2	1	2.1	1.1	1	2.1	2	1	2.3
3	1.3	1	1.7	1.9	1	2.2	1.4	1	2.5	1.9	1	2.6
4	1.6	1.1	1.7	2.1	1.1	2.1	1.5	1.1	1.7	2.1	1.1	2.1
5	1.6	1.1	1.5	2.1	1.1	2.2	1.6	1.1	2	2.1	1.1	2.3
6	0.9	0.9	0.9	1.9	0.9	1.5	1.1	1	1.8	2.1	1	2.1
7	1	1	0.5	2	1	1.5	1	1.0	1.5	2	1	2.1
Means	1.27	1.00	1.41	1.99	1.00	2.00	1.30	1.01	2.01	2.01	1.01	2.34

[1] Plantation locations: 1 = Centre Co., PA; 2 = Clearfield Co., PA; 3 = Somerset Co., PA; 4-5 = Lewis Co., NY; 6,7 = Hillsborough Co., NH.

[2] Discolored and defoliation ratings of West German: 0 = 0-10%; 1 = 11-25%; 2 = 26-60%; 3 = 61-99%; 4 = dead.

[3] Discolored and Defoliation ratings of American: 1 = 0-10%; 2 = 11-50%; 3 = >51%; 4 = dead.

[4] Coloration of West German and American: 0 = green; 1 = light green; 2 = yellow; 3 = bronze; 4 = red; 5 = brown.

Table 3.--Preliminary results of foliar analysis for Mg content for fifteen Norway spruce trees sampled within seven plantations located in three northeastern states. Analysis occurred for needle whorls 1986-1981 from both upper and mid-crown branches

	% Mg Foliar Content[2]											
	1986		1985		1984		1983		1982		1981	
	Up	Low	Up	Low	Up	Low	Up	Low	Up	Low	Up	Low
1	.16	.13	.15	.14	.16	.15	.17	.15	.18	.17	.16	.18
2	.07	.06	.04	.05	.05	.05	.04	.04	.04	.05	.04	.05
3	.04	.04	.03	.04	.03	.03	.03	.03	.03	.03	.03	.03
4	.05	.05	.03	.04	.03	.04	.03	.04	.03	.04	.04	.04
5	.06	.06	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04
6	.10	.10	.07	.08	.06	.07	.05	.07	.06	.06	.06	.07
7	.07	.07	.05	.06	.05	.06	.05	.05	.05	.05	.05	.05

[1] Plantation locations: 1 = Centre Co., PA; 2 = Clearfield Co., PA; 3 = Somerset Co., PA; 4, 5 = Lewis Co., NY; 6,7 = Hillsborough Co., NH.

[2] Needles by yearly internode were washed with CHCI$_3$ for 1 minute, rinsed with distilled water for 30 seconds, and then immersed 3 times in each of two successive beakers containing Ultrapure, ion-free, organic-free water. Needles were dried, ashed and analysed with an induced couple RF Plasma Emission spectrometer.

Table 4.--Magnesium content (meg/100 g and % base saturation) of soils in seven Norway spruce plantations in three northeastern states

	Avg. Meg/100 g[2]		Avg. % saturation	
Plantation	0-10	20-30	0-10	20-30
1	2.8	2.8	19.4	21.9
2	0.2	0.2	1.1	1.6
3	0.2	0.2	0.9	1.1
4	0.2	0.2	1.4	1.9
5	0.2	0.2	1.1	1.2
6	0.2	0.2	1.7	1.9
7	0.2	0.1	1.7	2.5

[1] Plantation locations: 1 = Centre Co., PA; 2 = Clearfield Co., PA; 3 = Somerset Co., PA; 4,5 = Lewis Co., NY; 6,7 = Hillsborough Co., NH.

[2] Soil samples were collected from 4 sides of each tree and each depth; composited by depth by tree. Numbers represent averages for entire plot at both depths.

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Vegetation Survey Pilot Study: Assessing Forest Damage on Whiteface Mountain, NY Using Remote Sensing Techniques

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Abstract

Thematic Mapper (TM) data were used to assess damage in spruce and fir forests on Whiteface Mountain, NY. Damage assessment images produced from these data portray a range of inferred damage levels which compare well with independently acquired ground-based measurements of forest damage, suggesting that this approach provides an accurate means of detecting, quantifying, and mapping forest damage. Using this technique, relatively high levels of damage are found in forests on Whiteface Mountain and the High Peaks region of the Adirondack Mountains, compared with moderate damage in the Green Mountains, VT, and low damage in the White Mountains, NH.

Introduction

Airborne and spaceborne remote sensing techniques utilizing Landsat Thematic Mapper (TM) and airborne Thematic Mapper Simulator (TMS) data have been shown to be of value in detecting and quantifying damage in spruce/fir forests in the northeastern United States (Rock et al. 1986; Rock and Vogelmann 1986; Vogelmann and Rock 1986; 1988). This approach has provided an accurate means of mapping damage associated with forest decline over large areas of Vermont and New Hampshire (Vogelmann and Rock 1988). The present study was developed to use TM data to detect and map levels of forest damage at selected sites in the northeastern United States currently under investigation as part of the NAPAP (National Acid Precipitation Assessment Program) Forest Response Program.

The primary objective of this project was to demonstrate the utility of using Landsat TM data for the purpose of detecting and quantifying forest decline damage in selected high-elevation spruce/fir forest stands on Whiteface Mountain, NY, Mount Mitchell, NC, and Mount Rogers, VA, as well as at a low elevation site, the Howland Experimental Forest, located near Howland, ME. A secondary objective of the study was to compare the relative levels of inferred damage detected at the various sites using this technique. This paper presents preliminary results from the Whiteface Mountain study site.

The approach included three distinct components: ground spectral data acquisition for the purpose of calibrating the TM data; processing of the TM data sets; and ground checking of the processed images for the purpose of determining the accuracy of the images produced. The first two components are described in this document. Because previously-acquired ground truth data were available for Whiteface Mountain, NY, a preliminary comparison of the imaged data with ground conditions is presented. The comparison of the images from the other sites with independently-acquired ground data is currently in progress.

Materials and Methods

Date Acquisition

Landsat Thematic Mapper data used in this study were acquired for Whiteface Mountain, New York (path 14, row 29), on August 4, 1984. The satellite data tapes were obtained through the EOSAT Company, c/o EROS Data Center, Sioux Falls, South Dakota 57198. The cost of the full TM scene was $3300.00.

The specific TM bands used in this study are centered at 0.56μm (band 2; 0.52-0.60μm), 0.66μm (band 3; 0.63-0.69μm), 0.83μm (band 4; 0.76-0.90μm), and 1.65μm (band 5: 1.55-1.75μm). These bands were used so that a TM band equivalent of the MSI (Moisture Stress Index) was developed, due to its sensitivity to canopy dryness (Rock et al. 1985; 1986).

Image Calibration

Data were calibrated using ground-based reflectance spectra acquired from spectrally and spatially homogeneous ground targets devoid of vegetation. The following targets were used for calibration of data for Whiteface Mountain: Whiteface Mountain Ski Area parking lot, Saranac Lake gravel pit, Mirror Lake (near Lake Placid), Sugarbush Ski Area parking lot (Vermont), and Green River Reservoir (Vermont). For these sites, field reflectance data were acquired using the HHRR (Hand Held Ratioing Radiometer) manufactured by Barringer, Inc. The HHRR acquires broad-band spectral data duplicating the spectral coverage of Landsat TM bands. Barium sulfate powder was used as a reflectance standard. Data were acquired from June to September, 1986.

Digital number (DN) values for each calibration target were then extracted from the TM data. To calibrate the data, field reflectance values and digital numbers from the imagery, respectively, were averaged for each band. Then, linear regression was used to develop an equation relating digital numbers to ground reflectance (Marsh and Lyon 1980; Conel et al. 1985). The DN values for each pixel in the entire scene were then multiplied by the equation of the least squares regression line for a given wavelength band so that image DN values were converted to reflectance values. Such calibration reduces the topographic influence on ratio-based indices such as those used in this study (Kowalik et al. 1983).

In order for the calibration procedure to work for a given scene, both light and dark targets should be used. This decreases error in calculating the linear regression equation for each band. Sandpits, gravel pits and concrete are examples of surfaces that are likely to be relatively spectrally bright, whereas water and asphalt are substances that are spectrally dark. For Whiteface

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Mountain, three bright and two dark targets were used (Figure 1). Each data point presented in Figure 1 represents an average of multiple values acquired from a single calibration target. The r^2 (or "goodness of fit") values ranged from 0.98 to 1.00 for Whiteface Mountain.

Data Processing And Image Analysis

Thematic Mapper data were processed at the Jet Propulsion Laboratory using the Dipix ARIES III and Vicar image processing systems on VAX 11/780 and VAX 11/750 computers. Vicar (Video image communication and retrieval) is an image processing system developed at JPL. Images of all field areas were processed using the same programs and many of the same parameters. A general purpose program "DIPID" was used to display images on a Dipix ARIES III display monitor. The individual programs used to calibrate, ratio, and create negatives of the images are described in the project Final Report (Rock et al. 1987b).

Ratioing bands. In previous studies (Rock et al. 1986; Rock and Vogelmann 1986; Vogelmann and Rock 1986; 1988) it was noted that regions with high band 5/band 4 values (MSI equivalent) correspond to regions of heavy forest damage. This ratio was therefore of interest in this study. The ratio of band 5 to band 4 was calculated for the field areas using the Vicar programs "RATIO" and "STRETCH". First, the program "RATIO" was used in the simple ratio mode to generate a band 5/band 4 image.

The gain values differed for every scene depending on the illumination conditions during the satellite overflight. The gain was adjusted in order to have a mean pixel value across the scene of approximately 128. Portions of the image were masked (i.e. pixel values set to zero) for pixels that represented lakes, rivers and cloud shadows. This step was necessary in order to eliminate areas where extremely low band 4 values would cause 'false alarms' of high damage to be evident due to the generation of high 5/4 ratios.

Density slicing. Density slices are images in which specific ranges of pixels in one band are assigned different colors in order to accentuate the spatial pattern of damage in a TM scene. Density slice images were generated for the band 5/band 4 image in all field areas using the Vicar programs "BOXFLT2" and "STRETCH". "BOXFLT2" applies a low-pass filter to an input image by taking the local mean of all pixels contained within a prescribed window centered at each pixel of the input image. This mean then replaces the input value. The effect of a box filter is to 'smooth' an image so that very localized phenomena (on the order of a few pixels) are deemphasized and large-scale patterns become more evident. A 3-pixel x 3-pixel "window of averaging" was used for all areas. After box filters were applied to the image, a color scale representing differing amounts of damage was constructed.

A table stretch was applied to all pixels in the image so that pixels having digital number values falling in a 'high damage' range were colored red, those falling lower damage ranges were colored orange, yellow green and blue, respectively. Using this color scheme, areas of red and orange were most apparent on the most exposed areas of mountain regions with yellow, green and blue were located in healthy, less exposed areas of the scene.

The result is a one-band image made using the ratio of band 5 to band 4. Different ranges of the ratio (i.e. different inferred damage levels) were assigned specific colors. This image aided in determining the spatial patterns of damage and also helped distinguish natural damage such as fir waves (lower ratio values) from other types of forest decline (higher ratio values).

Three-band images. Two types of false color three-band images have been produced for Whiteface Mountain:

1. False color infrared mimic: This type of image was made using one infrared band (band 4) in red color space, the red visible band (band 3) in green color space and the green visible band (band 2) in blue color space. This band combination covers the same portion of the spectrum as that covered by false color infrared (CIR) photography. This combination of bands was used to compare our method of damage classification to conventional aerial photographic damage assessment. The false color composite was also used for purposes of orientation to locate roads and specific field sites.

2. Damage assessment image: This type of image was made using the ratio of bands 5 and 4 in red color space, band 5 in green color space and band 2 in blue color space. This combination distinguishes conifer areas from hardwood areas and also distinguishes areas of low conifer damage from areas of high conifer damage.

Results

The following results from the Whiteface Mountain study site are presented in a descriptive fashion. Due to the color format of the images produced in this study, and the inability to reproduce them in the black and white format of this paper, it is impossible to present the full data set. A complete set of full-color images are provided in Rock et al. 1987a.

Ground data, in the form of ground transects, were acquired by Dr. Art Johnson and colleagues independent of this study. The data presented here must be considered as preliminary, since only data for a total of five ground transects have been supplied to JPL in a form that allows comparison with the TM data (see Discussion).

Image Analysis

CIR mimic. A false-color infrared (CIR) mimic image of Whiteface Mountain and vicinity was produced using bands 4, 3, and 2 in red, green, and blue color order. In this particular band combination, the red areas (high reflectivity in band 4) correspond to areas of hardwood forests; white and bluish areas (high reflectivity, particularly in band 2) correspond to fields or populated areas; and dark reddish-brown areas correspond to coniferous forests. This band combination is particularly useful in distinguishing between forested and non-forested areas and

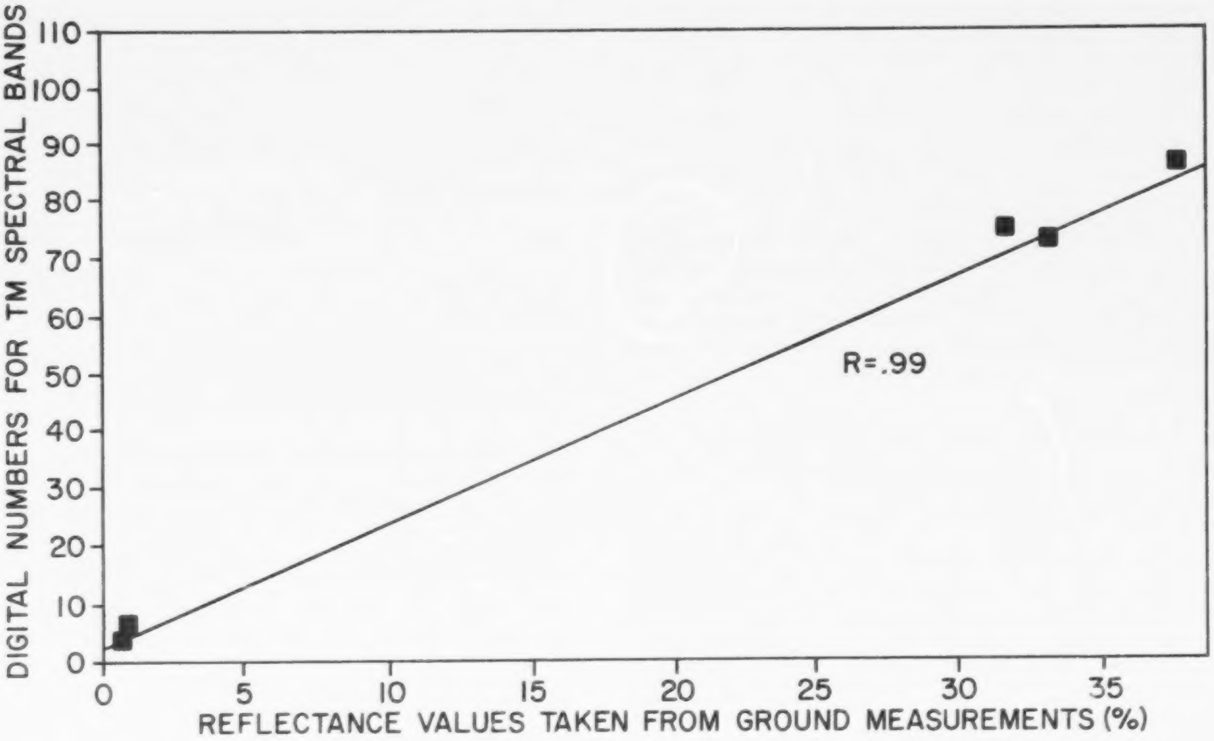


Figure 1.--Calibration line (least squares regression line) and correlation coefficient calculated using ground reflectance measurements and TM pixel DN values for TM band 7.

in discriminating between coniferous and hardwood forests. However, although ground photos and field work indicate that the spruce-fir forests vary greatly in state of health on the mountain, the coniferous areas in this band combination are dark - no obvious changes in the state of health can be detected using this band combination. However, a distribution map of conifer and hardwood stands could be produced using this image.

Damage assessment image. A damage assessment image of Whiteface Mountain was produced using the TM band 5/band 4 ratio assigned the red color space, band 5 the green color space and band 2 the blue color space. This band combination clearly distinguishes among rocks, roads and fields (white to pink), low-damage forested sites (either hardwoods or conifers, in various shades of blue to bluish-green) and high-damage forested sites (orange and red).

The damage assessment image agrees well with photographs taken from the ground. A photo taken from the summit of Whiteface looking northeast shows extensive fir wave development on the northwest slopes of the mountain. Fir waves are natural, crescent-shaped areas of dead trees caused by the prevailing winds (Sprugel 1976). A fairly large fir wave is seen extending between two portions of the road leading to the summit. This fir wave can be seen clearly in the damage assessment image, extending from near the summit to the northeast between the hairpin portions of the road. Various other fir waves visible on the northwestern slope of Whiteface Mountain can also be seen in the damage assessment image. Areas exhibiting high band 5/ band 4 ratios, but showing no crescent-shaped fir wave patterns can also be seen in the image. These damaged areas are likely to be attributable to forest decline, and are referred to here as "other" damage. The CIR mimic does not discriminate either the fir wave damage or other damage nearly as effectively as the damage assessment image. The damage assessment image is clearly superior to the CIR mimic in determining the state of health of forests on Whiteface Mountain.

Color density slice image. A comparison of the color density slice image with the damage assessment image indicates that different levels of high damage may be discriminated in the spruce/fir forests on Whiteface Mountain. Within the fir wave areas, inferred damage levels may not be as great as those seen in the "other" areas of damage (considered here to be areas of spruce damage). Table 1 presents summary band 5/4 ratio values supporting this observation. The data presented in Table 1 are preliminary, and further work on assessing the spectral differences between these and other types of damage is needed.

Qualitative comparison with ground assessment. The damage assessment image appears to correlate well with independent, ground-based measurements made by Art Johnson and co-workers of spruce and fir mortality. A plot of percent spruce/fir mortality for three ground assessment transect data points located on the northwest slopes of Whiteface Mountain were compared with the image. The ground transect data sets were located on topographic maps and transferred on to the damage assessment image. The data provided includes the types of trees present at each point along every transect, both live and total basal area of each species and many other parameters defining the biomass at each point.

Table 1.--Pixel DN ratio values for both fir wave and other high damage zones.

Area	Number of pixels	5/4 ratio (Average)	Standard deviation
Fir wave high damage zone	21	112.5	± 5.6
Other high damage zone	23	120.4	± 5.3

There is considerable variance in the mortality measurements for all transects, but certain patterns of increasing and decreasing levels of damage are clear. From the damage assessment image with the three ground transects, it can be predicted that the western-most transect would pass through an area of fairly low damage, since the transect is in an area assigned the blue to blue-green colors, signifying healthy forest, until it enters a fir-wave zone near the ridge line. Johnson's dead basal area data for this transect range from 0% to 15% for spruce and fir until near the highest elevation point on the transect (1100m), where a value of 30% is recorded. From the image, the transect enters the area of fir wave damage at approximately 1050m.

On the image the middle transect starts in an area of fairly low damage at approximately 730m, and then passes through an isolated region of higher damage at 850m, and then proceeds back into lower damage areas until entering the fir-wave area at approximately 1000m (obscured on the image due to a cloud shadow). The ground transect data follow this pattern exactly. A spike of extremely high spruce and fir mortality (90%) is found between 825m and 950m elevations, and ranging from 25% (healthy areas of fir waves, according to the image) to 95% dead basal area (damaged portions of waves) above 1000m. The northern-most transect on the image passes through a low-damage area until the elevation of the road at approximately 950m, where it enters a fir-wave area. The ground data record no (0%) damage until a point located at 975m, and the damage ranges from 5% to 90% in a pattern which matches the fir-wave patterns on the image.

Quantitative comparison with ground assessment. When an attempt was made to compare band 5/4 ratio values with specific points on the ground transects, a strong correlation was not seen. The individual pixel corresponding to a particular mortality measurement could not be extracted. The reason is that the mortality measurements of Johnson and co-workers were taken in a single five-meter circular plot at each point along the transects. Thus, the area of the ground-based plot was 78.5 square meters, whereas the area coverage by one TM pixel was 900 square meters - an order of magnitude difference in size. Since the ground conditions are highly heterogeneous in terms of damage and percent mortality at any given site based on image analysis, a direct comparison of ground data and pixel ratio values could not be made.

East-west damage gradient. Histograms of TM band 5/4 ratios were obtained for only the conifer forests on Whiteface Mountain. A damage rating used to assess damage in the Green Mountains and White Mountains (Vogelmann and Rock 1988) was used to assess the relative damage in Adirondacks. This damage assessment takes into account numbers and TM 5/4 ratios of low, medium, and high damage pixels (based on field work done on or near Camels Hump, Vermont) and is basically an assessment of damage based on the relative amount of low damage pixels vs. high damage pixels. The equation used to calculate the damage rating is as follows:

$$\text{Damage Rating} = \frac{(100 - \%\ \text{low damage pixels}) + \%\ \text{high damage pixels}}{2}$$

It should be made clear that the damage rating is a relative measure of forest damage and should not be confused with percent mortality. A complete description of the method can be found in Vogelmann and Rock (1988). Table 2 is a summary of the damage ratings for the three mountain ranges.

Discussion

The high correlation seen between image data and ground-acquired mortality data suggests that remotely sensed data from TM provides an extremetly accurate means of detecting, quantifying, and mapping forest damage. The fact that fir wave damage and "other" damage areas may be separable both spectrally and spatially suggests that these two types of damage may be mapped separately.

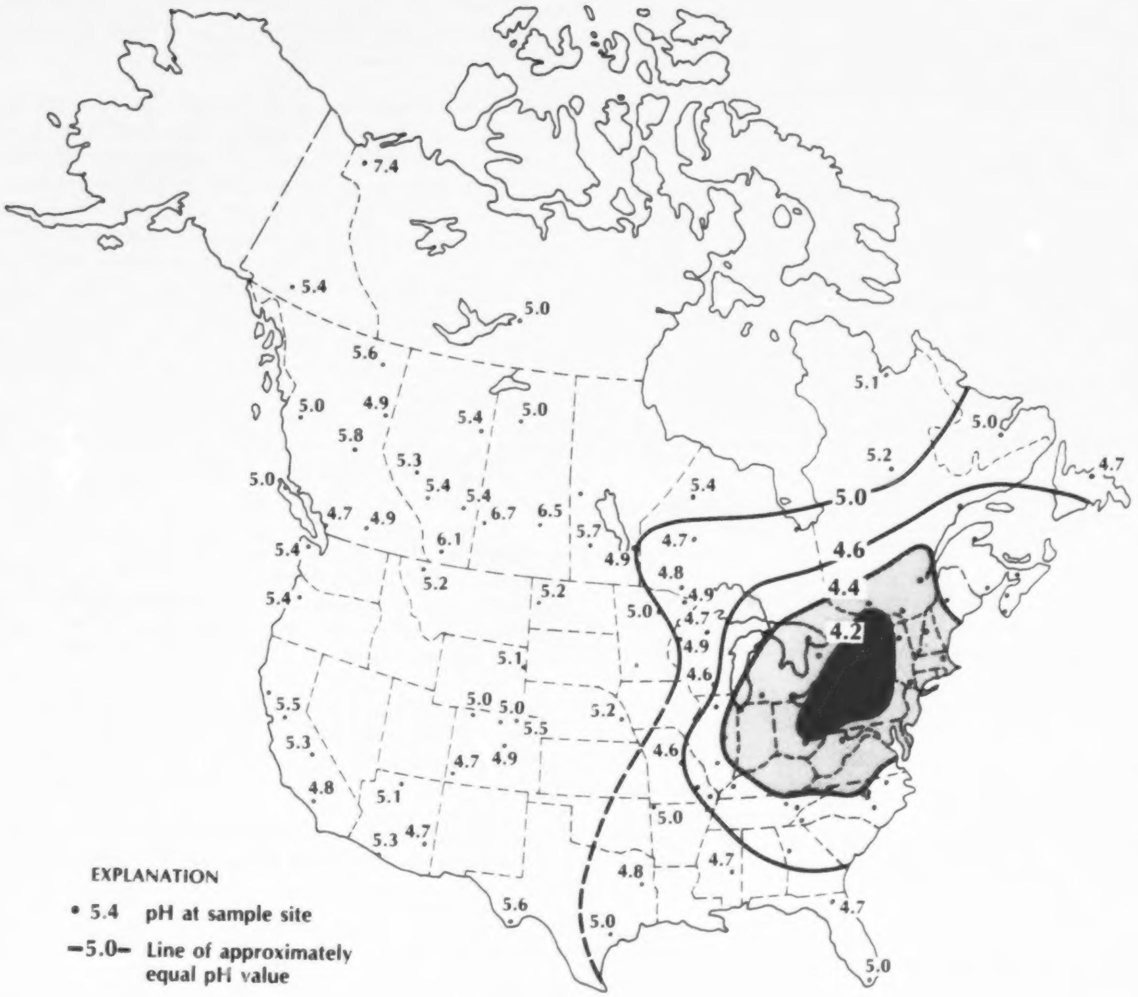
Comparison between the ground-based measurements of mortality and the damage assessment image could be done on a qualitative basis only. In addition to the problem of comparison of a small point on the ground with the much larger TM pixel, attempting to actually locate the ground point with precision on an image is problemmatical. Future ground assessment activities, if they are to be of value in providing ground truth for determining the accuracy of remotely sensed data, must cover a large enough area (a minimum of four pixels - nine pixels would be ideal) so that adequate comparisons may be made. Because such a ground assessment effort will be very labor intensive, it is proposed here that remote sensing data be used to select areas to be assessed. For the most part, existing ground data are of use in qualitative comparisons with remotely sensed data sets such as those desribed here, but of little value in quantitative assessment and calibration of such data.

At this point, comparisons have been made between the mountains in the northeast only. It was possible to compare mountains in the northeast because enough data sets were available to provide 'overlapping' information - TM data could be calibrated from one scene to another. Also, detailed ground work has been done in the northeast and this makes it possible to determine what damage ratings correspond to certain DN values. With only isolated data sets for the southeast and no detailed ground information available to us at this time, the kind of a comparison made at Whiteface Mountain is not possible.

A clear gradient of inferred damage is seen when the Adirondacks are compared with the Green Mountains of Vermont and the

Table 2.--Conifer damage in the Adirondacks, Green Mountains and White Mountains.

Site	Elev (m)	% low damage pixels	% medium damage pixels	% high damage pixels	Damage rating
Adirondacks					
Whiteface	1484	8.6	12.7	78.7	85.1
High Peaks Area	1268	2.3	6.8	90.9	94.3
Green Mnts					
Camels Hump	1244	26.5	20.7	52.8	63.2
Mt. Abraham	1260	25.6	25.6	48.9	61.7
Broadloaf	1165	37.9	24.6	37.5	49.8
White Mnts					
Mt. Moosilauke	1464	72.3	16.8	10.9	19.3
Lafayette	1585	63.9	19.0	17.0	26.6


EXPLANATION
• 5.4 pH at sample site
–5.0– Line of approximately equal pH value
7.4
5.4
5.0
5.6
4.9
5.0
5.8
5.4
5.0
5.3
5.4
5.4
6.7
6.5
5.0
4.7
4.9
6.1
5.7
4.9
5.4
5.2
5.2
5.4
5.4
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4.9
4.6
5.1
5.0
5.2
4.7
5.0
4.6
4.4
4.2

Figure 2.--Annual average (precipitation-weighted) pH values of wet deposition for the United States (NAPAP 1983).

White Mountains of New Hampshire. The highest damage is seen in the Adirondacks, with the lowest damage seen in the White Mountains (Table 2). This spatial pattern of damage corresponds well with concentration and distribution patterns of a variety of pollutants and rainfall acidity values (Figure 2) for the Adirondacks, Green Mountains, and White Mountains. Remote sensing data acquired by satellite provide a unique regional perspective from which to study forest damage patterns.

A final point should be made regarding the value of using satellite remote sensing data in the study of forest damage. Due to its regional scope, assessment accuracy, and relative low cost, remote sensing techniques might be best used to focus and coordinate current ground activities and assist in the location of future studies. this would allow for the most efficient utilization of limited funding, manpower, and time.

Summary

The TM band 5/ band 4 'damage assessment' images appear to be a very accurate means of determining the state of health of high-elevation conifer forests, based on qualitative comparisons of the image with ground photos and independent, ground-based measurements of spruce and fir mortality on Whiteface Mountain. Fir waves have been detected on the western slopes of the mountain and can be separated from areas of 'other' damage using the damage assessment image. A west-to-east gradient of increasing damage from the Adirondack Mountains through the Green Mountains to the White Mountains has been detected.

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Historical Impacts on Red Spruce and Balsam Fir in the Northeastern United States

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Abstract

Red spruce, ***Picea rubens*** *Sarg. and balsam fir,* ***Abies balsamea*** *(L.) Mill. in the Northeastern United States have been impacted by many factors during the past 150 years. Logging and bark beetles removed most of the old-growth timber by the early 1900's. In the mountainous areas, logging was often followed by fires and soil erosion. Red spruce did not return to many sites it once occupied. It returned to the upper slopes, but the conditions there are not optimum for its growth. Four spruce budworm outbreaks occurred, mostly in Maine. The last outbreak left thousands of acres of dead trees. Wind sometimes caused catastrophic losses and continually damages trees on exposed sites. Widespread mortality was associated with winter injury and drought in the 1960's. A "decline" since the 1960's has been due at least in part to bark beetles, pathogens and wind. As current stands mature, the impacts of bark beetles, pathogens and wind can be expected to increase.*

Introduction

In this paper, we briefly review the more important factors that have affected red spruce, *Picea rubens* Sarg., and balsam fir, *Abies balsamea* (L.) Mill., in the Northeastern United States during the past 150 years. This review of logging, fire, insects and other factors will help in the interpretation of present forest conditions, and prediction of future changes.

Logging

Logging of red spruce first began on a large scale in the mid-1800's after supplies of the more valuable and accessible eastern white pine, *Pinus strobus* L., were exhausted (Murphy 1917; Wood 1935). The red spruce on the lower slopes was cut first and then the upper slopes were cut (Chittenden 1904; Korstian 1937; Westveld 1931). Initially, balsam fir was not as marketable as spruce, and it was often left. But, by the early 1900's, use of balsam fir for pulpwood and lumber increased (Oosting and Reed 1944; Zon 1914), and many landowners in the Northeast were clearcutting, leaving only occasional spruce and fir trees over 5 inches in diameter (Westveld 1931). Clearcutting was a common practice even on the upper slopes (Chittenden 1904). Only a few old growth stands survived this era of heavy logging (Brown 1958; Korstian 1937; Oosting and Billings 1951). In addition to removing most of the old-growth timber, logging had several other lasting effects. For example, in New Hampshire, extensive areas of red spruce that grew on deeper and better soils of the lower slopes converted to hardwoods following clearcutting and fire (Chittenden 1904). In other areas, clearcutting favored increases in balsam fir (Zon 1914; Murphy 1917; Oosting and Reed 1944), which tends to be more vulnerable than red spruce to insect and disease damage. Flooding killed thousands of acres of spruce in the Adirondacks in the 1800's when dams were built to float logs (Hough 1882). In West Virginia, between about 1869 and 1899, the combination of logging, fire and bark beetles reduced the area of pure spruce forest from 750,000 acres (304,000 ha) to 225,000 acres (91,000 ha) (Hopkins 1899). Logging and fire together appear to have been responsible for practical elimination of red spruce in west-central Virginia (Pielke 1980).

Fire

Fires were infrequent in the original forest of red spruce and balsam fir, "fire rotations" averaging 100 years or more (Heinselman 1978). Indians were not known to deliberately set fires in areas of spruce and fir in northern New England or the Adirondacks, and the occasional fires probably occurred as a result of lightning or escaped camp fires (Day 1953).

When the mountain slopes were logged, fire became a major problem (Diebold 1941; Chittenden 1904; Pielke 1980; Widner 1968). In the Adirondacks, for example, numerous fires burned over many thousands of acres in 1903, 1908, and 1913, usually starting in cutover lands by sparks from locomotives (Diebold 1941; Widner 1968). Fires were also a serious problem following logging in other areas of the Northeast (Chittenden 1904; Hale 1958; Hopkins 1899; Widner 1968). The large amounts of dry fuel left by logging led to intense fires, and the same areas sometimes burned repeatedly (Chittenden 1904). The humus layer of the soil was greatly reduced in logged over and burned areas resulting in serious erosion of already scarce mineral soil (Diebold 1941; Chittenden 1904; Korstian 1937). Advanced reproduction of red spruce and balsam fir was also destroyed (Chittenden 1904; Pielke 1980). Hardwood reproduction was favored under these conditions (Chittenden 1904).

The largest fire ever recorded in North America affected the spruce-fir type. The "Great Miramichi" fire of October 1825 burned about 3,000,000 acres (1,215,000 ha) in Maine and New Brunswick (Plummer 1912). It occurred after an extended drought (Plummer 1912), and started when fires, set by settlers to clear their land, burned out of control (Wein and Moore 1977).

Organized fire protection began in most states around 1910 (Widner 1968). With fire protection, and reduced logging on the slopes, the acreage burned annually is comparatively small today (Fahey and Reiners 1981; Haines et al. 1975; Plummer 1912; Widner 1968).

Insects

Widespread mortality has occurred from several bark beetle and spruce budworm outbreaks. Bark beetle outbreaks across the

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Northeast in the 1800's caused the loss of billions of board feet of mature and overmature spruce (Hopkins 1899, 1901). Three spruce budworm outbreaks since 1878 caused mortality of red spruce and balsam fir over thousands of acres, primarily in Maine.

The spruce beetle, *Dendroctonus rufipennis* Kirby caused widespread mortality across New York and northern New England during a series of outbreaks beginning about 1830 or earlier and continuing until at least 1900 (Graves 1899; Hopkins 1901; Hough 1882; Packard 1884, 1890). Widespread mortality also occurred from bark beetles to the south. In Virginia, serious spruce mortality attributed to bark beetles occurred about 1835-40 (Hough 1882). In West Virginia in 1882-86, heavy spruce mortality was attributed to the four-eyed spruce beetle, *Polygraphus rufipennis* Kirby (Hopkins 1899).

Johnson (1898) reported heavy mortality of spruce in Pennsylvania in 1882-97, which he attributed to the four-eyed spruce beetle and the spruce beetle. In 1890-92 the southern pine beetle, *Dendroctonus frontalis* Zimm., caused extensive mortality of spruce in West Virginia (Hopkins 1899). During the 1800's, large areas of logging slash, fire damaged trees, and overmature spruce favored development of damaging bark beetle outbreaks. Bark beetle damage decreased after the 1800's, except in a few local areas where old, large trees remained. The spruce beetle killed a large amount of remaining mature and overmature spruce in the Adirondack and Catskill Mountains of New York in 1934-50 (New York State Conservation Department 1955). Spruce beetle outbreaks have recently been reported in older stands in the Adirondacks and New Hampshire (USDA Forest Service 1984; McCreery et al. 1986; Souto and McCreery 1987).

The spruce budworm, *Choristoneura fumiferana* Clem., has been at least as damaging as the bark beetles. An outbreak of the spruce budworm occurred along the coast of Maine in 1878-87, and an estimated one-third of the spruce and fir from Portland, Maine, east to the Canadian border was killed (Packard 1881, 1883; USDA 1893).

The next spruce budworm outbreak occured in 1910-19 and was more widespread. An estimated 27 million cords were destroyed in Maine, of which 30 percent was spruce and 70 percent was fir (Pistell and Harshberger 1979). Some mortality also occurred in Coos County of northern New Hampshire (New Hampshire Forestry Commission 1924). An outbreak started in New York and Maine in the mid-1940's, quickly subsiding in New York after causing some tree mortality (New York State Conservation Department 1947). The outbreak continued in Maine through the 1950's (Kettela 1983; Hardy et al. 1986), but widespread mortality did not occur apparently because of insecticide protection (Pistell and Harshberger 1979).

The most recent outbreak of the spruce budworm began about 1970 (Kettela 1983; Hardy et al. 1986), reached a peak in the late 1970's and began to subside in the early 1980's. Defoliation in Maine occurred on several million acres each year through 1985, dropping to 600,000 acres (243,000 ha) in 1986 (USDA Forest Service 1987). The outbreak extended across most of northern Maine, and into northern New Hampshire and northeastern Vermont. In Maine, more than half of the balsam fir died on 300,000 acres (121,000 ha) (Kucera and Taylor 1986). Tree mortality also occurred in Vermont and northern New Hampshire (Kucera and Taylor 1984).

Balsam fir reproduction is favored by open stand conditions. Consequently, one of the lasting effects of spruce budworm outbreaks and logging has been to reduce the proportion of red spruce and increase the proportion of the less desirable balsam fir (Blais 1965; Spaulding and Hansbrough 1944; Swaine 1933; Westveld 1953.)

Pathogens

Several serious pathogens occur in red spruce and balsam fir. The root-rotting fungus, *Armillaria mellea* (Vahl:Fr) Kummer, has been associated with mortality of both red spruce and balsam fir (Carey et al. 1984; Hepting 1971). Eastern dwarf mistletoe, *Arceuthobium pusillum* Peck, causes growth loss and mortality in older stands of red spruce (Hawksworth and Shigo 1980). The fungus, *Valsa kunzei* Fr., is associated with branch mortality of declining red spruce in West Virginia (Mielke et al. 1986). Several fungi cause root and butt rots in balsam fir making as many as half of the trees unuseable at 70 years of age (Spaulding and Hansbrough 1944).

Adverse Weather

Hurricanes and other wind storms have caused serious damage. The most striking example in recent times is the hurricane that struck New England on September 21, 1938 damaging over 15 million acres (6 million ha) of forests (Natti 1979; Brooks 1939). In northern New Hampshire and Vermont, much spruce and hardwood was destroyed (Clepp 1938). A wind storm that struck New York on November 25, 1950 caused heavy damage in virgin timber at lower elevations in the Adirondacks with blow-down in excess of 25 percent on 423,000 acres (171,000 ha) (New York State Conservation Department 1951). A heavy snow followed by severe wind destroyed trees over hundreds of miles in Maine in November 1871 (Hough 1882). Wind-caused root damage from the same storm may have reduced tree vigor which in turn may have contributed to an extensive outbreak of bark beetles in Maine beginning about 1876 (Hough 1882).

Red spruce and balsam fir are susceptible to windthrow because of their shallow root systems (Blum et al. 1983; Graves 1899; Zon 1914). Stem breakage is common in balsam fir, particularly in large trees, which usually have serious stem decay (Behre 1921; McLintock 1954).

Graves (1899) reported that damage done by wind in the Adirondacks is "very great" and that spruce on southwest facing slopes exposed to the prevailing winds and heavy storms frequently suffer windfall before reaching maturity. Wind damage to red spruce overstory trees has been common in the Catskill

Mountains of New York resulting in stand openings (McIntosh and Hurley 1964). Blow-down has been a major factor in the spruce-fir stands along the coast of Maine (Davis 1966).

Red spruce and balsam fir growing in rocky soil on exposed sites in the northern Appalachians suffer root damage due to root movement with the windy conditions common on these sites (Harrington 1984, 1986; Stone 1977). Root wounds are invaded by fungi which cause further damage to the roots (Harrington et al. 1984). Wind, in combination with rime ice, damages shoots (Harrington 1986). The damage to the roots and crowns can lead to growth reduction and mortality with greater damage expected in older stands (Harrington 1986).

In the higher elevations of the Northeast, where balsam fir occurs in almost pure stands, mortality and regeneration occur in a wave-like pattern (Sprugel 1976). The mechanism by which the front of old trees in the wave is killed is not completely understood, but branch breakage due to rime ice and wind, loss of foliage due to icing, and winter desiccation are factors that may be involved (Marchand 1984; Sprugel 1976; Sprugel and Borman 1981).

Tree damage or mortality has often been associated with winter injury. Curry and Church (1952), reported damage to red spruce and balsam fir in the Adirondacks in 1947-48 as a result winter injury and drought. During 1959-68 there were many reports of damage and mortality in red spruce and, in some cases balsam fir, at higher elevations from Maine to New York as a result of winter injury and, possibly, drought (Weiss et al. 1985). The most extensive winter injury in Maine occurred in March 1962, after which red spruce died along the crests of many mountains in western Maine. Drought and shallow soils were thought to be contributing factors. Similar damage occurred to red spruce in New Hampshire and Vermont.[1]

In New Hampshire, Hadfield (1969) reported that by 1969 most of the mortality caused by the winter injury had ended. He estimated the total affected area to have been up to 30,000 acres (12,000 ha). This damage coincided with the start of a "decline" of red spruce and balsam fir reported in these same forests by Johnson and Siccama (1983).

Decline

A region-wide "decline" of red spruce and balsam fir is reported in mountainous areas of the Northeast. The decline is characterized by tree deterioration and high mortality, without an apparent cause in most cases. Tree deterioration or high mortality in red spruce was reported from the Catskill Mountains in New York, 1960-62 (McIntosh and Hurley 1964); Camels Hump, Vermont, 1963-65 (Siccama 1974); White Mountains, New Hampshire and Green Mountains, Vermont, 1978; [2] [3] Crawford Notch, New Hampshire, 1979-80 (Foster and Reiners 1983); Whiteface Mountain, New York, 1964-82; (Scott et al. 1984); Green Mountains, Vermont, 1964-79 (Siccama et al. 1982); New York, Vermont and New Hampshire, mid 1960's-early 1980's (Johnson and Siccama 1983); West Virginia, 1985 (Mielke et al. 1986), Massachusetts, 1984-85 (MacConnell et al. 1986); New York, Vermont and New Hampshire, 1984 (Weiss et al. 1985).

A decline in growth rate of red spruce in New England and New York also began in the 1960's (Hornbeck and Smith 1985). The decline in growth rate is not restricted to the mountainous areas (Hornbeck et al. 1986).

Although a complete explanation for the decline is lacking, at least some of the factors involved are now known. Several of the historically important agents have been associated with recent tree deterioration and mortality. There are recent reports of damage by the spruce beetle in the Adirondacks and New Hampshire (McCreery et al. 1986; Souto and McCreery 1987); by eastern dwarf mistletoe in the Adirondacks and New Hampshire (Hawksworth and Shigo 1980; Souto and Hawksworth 1987); by Armillaria root rot in lower elevations in New England and New York (Carey et al. 1984); by wind in higher elevation sites in New Hampshire (Harrington et al. 1986); and by Cytospora canker, four-eyed spruce beetle and Armillaria root rot in West Virginia (Mielke et al. 1986). As discussed earlier, winter injury, and possibly drought, caused widespread mortality in the 1960's. The decrease in growth rates is due at least in part to natural maturation of the spruce-fir forests (Hornbeck et al. 1986). Spruce budworm damage adversely affected growth rates where it occurred; however, it was not a factor in most of the mountainous areas.

Several other factors may be involved in the decline. Drought has been reported at numerous times over the past 150 years, often as a contributing factor to fires, bark beetle outbreaks and winter damage, and some workers have suggested a possible relationship between the current decline of red spruce and climatic change or drought (Siccama 1974; Johnson et al. 1985; Johnson and McLaughlin 1986). Red spruce may be particularly vulnerable to climatic change because of its genetic uniformity (Wright 1955). Acid deposition may be a contributing factor in the decline (Johnson and Siccama 1983). However, a causal relationship between air pollutants and decline of red spruce has not been established (Woodman and Cowling 1987).

Summary and Discussion

During the last 150 years, logging, insects and adverse weather have had major impacts on red spruce and balsam fir in the Northeastern United States. In the mountainous areas, logging and bark beetle outbreaks almost eliminated the original forest, and red spruce did not return to many sites it once occupied. Red spruce returned to the upper slopes, but the conditions there are not optimum for its growth (Chittenden 1904; Korstian 1937).

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[1] Stark, D.A. Personal communication. Maine Forest Service, Augusta.

[2] Weiss, M.J. Memo to J. Jordan, Supervisor, White Mountain National Forest, Laconia, NH; Sept. 6, 1978.

[3] Weiss, M.J. Memo to J. McArdle, Forest Supervisor, Green Mountain National Forest, Rutland, VT; Oct. 2, 1978.

The spruce beetle has periodically caused mortality in the few remaining old-growth stands of red spruce. Spruce budworm has caused damage during four outbreaks, mostly in Maine. The last outbreak left thousands of acres of dead balsam fir and spruce in Maine, far northern New Hampshire and northeastern Vermont. The spruce budworm and logging have created openings favorable to increases in the less desirable balsam fir. Red spruce and balsam fir on the upper slopes have been impacted by winter injury, wind, and possibly drought. A recent "decline" has been due at least in part to insects, pathogens and wind.

In the future, bark beetle outbreaks will continue to occur in the few remaining old spruce stands. Outbreaks can also be expected in the many spruce stands protected from logging and now reaching maturity. Losses from decay fungi will increase with increasing stand age. Spruce budworm outbreaks will occur periodically, although the impact may be less than in the past if the commercial forest in these areas is managed on a shorter rotation. Stands on exposed sites in mountainous and coastal areas will continue to be subjected to extreme weather conditions, and wind damage can be expected to increase as the forests mature. Most fires will be small. Large fires may occur during prolonged drought periods.

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Changes in the Montane Spruce-Fir Forest of Camels Hump, Vermont

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Abstract

Forest surveys performed between 1965 and 1986 document significant reductions in density and basal area for red spruce on Camels Hump mountain, Vermont over this time period. All size classes of red spruce trees (≥ 2 centimeters diameter at breast height) have declined since 1965. Balsam fir shows a significant reduction in basal area, but not in density between 1965 and 1986. Overall vigor of the remaining red spruce population, measured by degree of defoliation, has consistently declined between 1979 and 1986. Balsam fir vigor has remained approximately constant over this same time period. Regeneration of both red spruce and balsam fir, while down from levels recorded in 1965, have increased since 1983. Birch seedlings have increased over 1000% since 1965, most probably in response to increased light reaching the forest floor.

Introduction

In the mid-1960's, Camels Hump, a 1248 m peak in the northern Green Mountains of Vermont, was selected for long-term ecological studies. Sugar maple (*Acer saccharum* Marsh.), American beech (*Fagus grandifolia* Ehrh.) and yellow birch (*Betula alleghaniensis* Britt.) occupy the lower slopes from 550 m to 730 m. Red spruce (*Picea rubens* Sarg.), balsam fir (*Abies balsamea* [L.] Mill.), and white birch (*Betula papyrifera* Marsh var. *cordifolia* [Regel.] Fern) gradually replace the northern hardwood species of the lower elevations between 730 m and 850 m and form a fully dominant montane coniferous forest between 850 m and 1100 m. Above 1100 m balsam fir forms nearly pure stands.

The forests, soils and climate of Camels Hump were initially described by Siccama (1968, 1974). Subsequent forest surveys in 1979 (Siccama *et al.* 1982) and 1983 (Vogelmann *et al.* 1985) show declines in density and basal area for red spruce in all size classes. Downward trends in other tree species were apparent in the 1983 survey (Vogelmann *et al.* 1985). This paper reports the results of the 1986 survey by detailing the long-term (1965-1986) and short term (1983-1986) changes that have occurred in red spruce and balsam fir in this montane coniferous forest.

Methods

Forest inventory methods used were the same in 1965, 1979, 1983 and 1986. A detailed description of field methods appears in Vogelmann *et al.* 1985. Counts were made and dia measured for all trees ≥ 2 cm diameter at breast height (d.b.h.) in 3.0 m x 30.5 m plots (10' x 100') at approximately 60 m elevational intervals from 550 m to 1160 m on Camels Hump mountain, Vermont. Woody stems < 2 cm d.b.h. were counted in 6 one-meter-squared plots located within each of the larger plots. Sample plots were from approximately the same areas in all years. Permanent plots were established in 1983 and were subsequently remeasured in the 1986 inventory.

Defoliation based vigor/mortality estimates were made for each red spruce and balsam fir tree beginning with the 1979 inventory.
Class designations were:
Class 0: <33% defoliation
Class 1: 33 - 66% defoliation
Class 2: >66% defoliation
Class 3 and 4: Standing dead trees
Both primary and secondary foliage were included in the estimation of defoliation.

Density (live stems/hectare) and basal area (m^2/hectare) were calculated for each species and sampling year. Only plots within the elevational distribution of a species were used in the calculations. The use of permanent plots in the two most recent surveys reduced the sampling error used to determine the significance of observed differences. This heterogeneity with respect to error prevented a pooled analysis of variance utilizing the four sampling years. Separate analyses of variance controlling for potential elevational differences were thus utilized to test the null hypotheses of no net change between (a) 1965 and 1986 and (b) 1983 and 1986.

Results

Density and Basal Area 1965-86

Estimates of density and basal area were significantly lower ($p \leq 0.05$) for red spruce in 1986 than in 1965 (Table 1). Significant declines were observed in balsam fir basal area, while only decline trends were found in density. White birch declines in both density and basal area were non-significant during this time period.

Density and Basal Area 1983-86

Lowered density estimates were measured for red spruce, balsam fir, and white birch between 1983 and 1986. Significant declines occurred only in balsam fir and red spruce. Basal area estimates were lower between 1983 and 1986 for red spruce and balsam fir, and slightly higher for white birch. Only the reduction in red spruce basal area was significant.

Size Class Distributions

Density of red spruce has shown reductions in all size classes of live trees ≥ 2 cm d.b.h. between 1965 and 1986 (Figure 1). Balsam fir was exhibited a loss of density in smaller trees (2-8 cm d.b.h.) and slight increases in larger trees. White birch stems decreased in all size classes except for a slight increase in 8-10 cm d.b.h. trees.

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Table 1.--Estimated density and basal area for dominant tree species ≥ 2 cm d.b.h. (based on natural distributions) for the montane conifer zone on Camels Hump, Vermont.

DENSITY (live trees/ha)

	Elevation	**1965**	**1979**	**1983**	**1986**	**95% CI**[a]	NET CHANGE (%) **1965/1986**	**p**[b]	NET CHANGE (%) **1983/1986**	**p**
Red spruce	790-1035m	560	264	286	194	± 119	-366(-65%)	< .01	-92(-32%)	< .01
Balsam fir	850-1160m	1950	1999	1842	1710	± 222	-240(-12%)	.41	-132(-07%)	.03
White birch	790-1160m	306	242	189	160	± 59	-146(-48%)	.17	-29(-15%)	.35

BASAL AREA (live m²/ha)

	Elevation	**1965**	**1979**	**1983**	**1986**	**95% CI**	NET CHANGE (%) **1965/1986**	**p**	NET CHANGE (%) **1983/1986**	**p**
Red spruce	790-1035	8.21	4.75	2.54	2.13	± 2.20	-6.08(-74%)	< .01	-0.41(-16%)	< .01
Balsam fir	850-1160m	15.20	14.85	13.28	12.90	± 1.17	-2.30(-15%)	.05	-0.38(-03%)	.72
White birch	790-1160m	4.58	5.17	3.32	3.38	± 1.12	-1.20(-26%)	.18	+0.06(+02%)	.75

[a] 95% Confidence interval for mean based upon a pooled estimate of variance.

[b] Significance values are those associated with testing the null hypotheses of no change by the analysis of variance controlling for potential elevational difference.

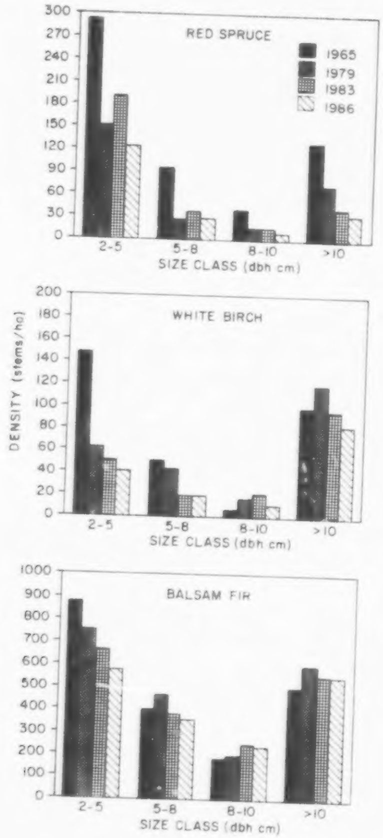

Figure 1.--Density of red spruce, balsam fir, and white birch by size class on Camels Hump, Vermont, in 1965, 1979, 1983, and 1986.

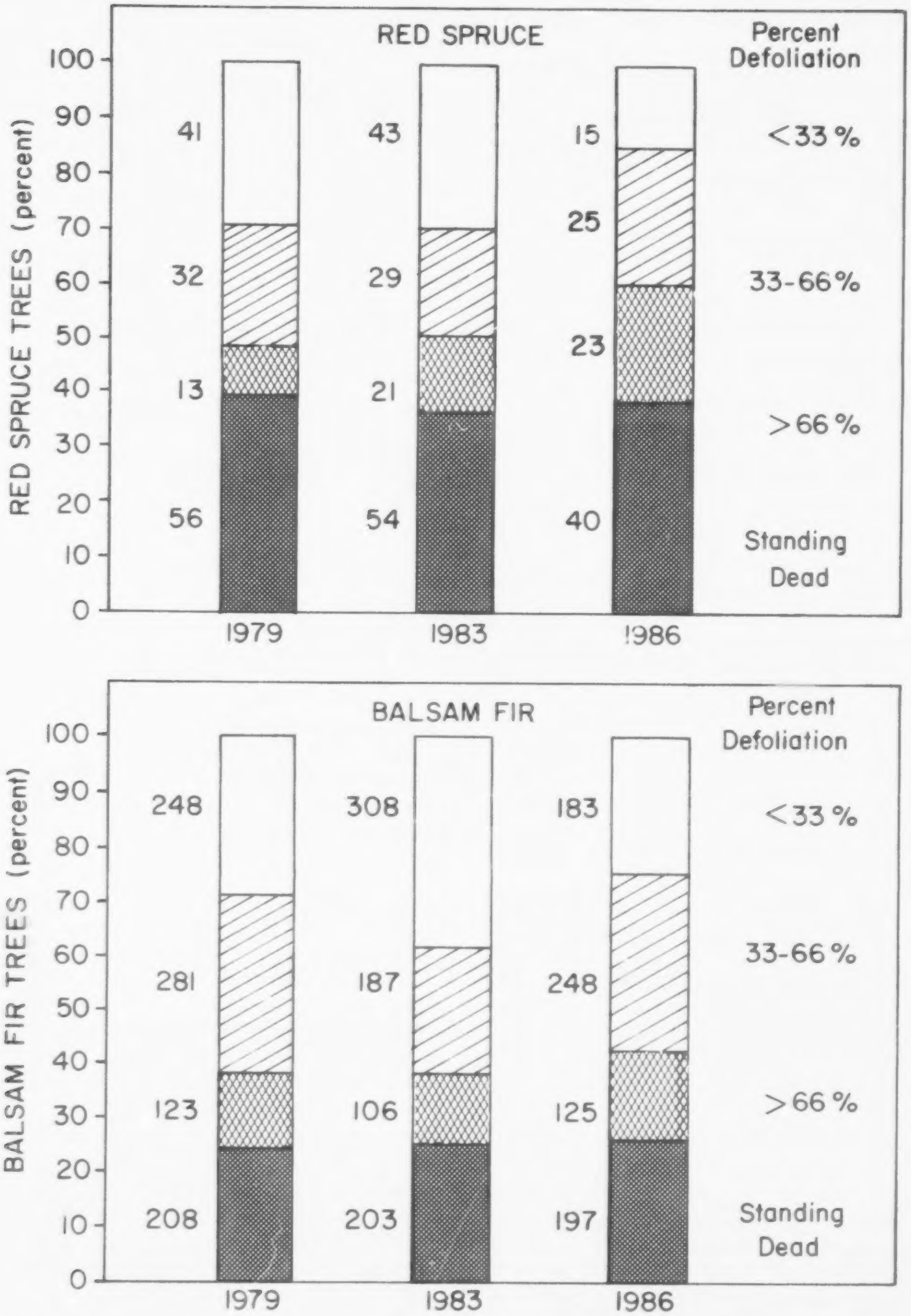

Figure 2.--Percentage of red spruce and balsam fir trees by defoliation class in 1979, 1983, and 1986 on Camels Humps, Vermont, U.S.A. Actual tree counts (n's) are given to the left of each bar segment. Note: Stacked bars.

Table 2.--Estimated density for tree species < 2 cm dbh in m² plots (based on natural distribution) on Camels Hump, Vermont.

		DENSITY (seedlings trees/ha)				NET CHANGE(%)	NET CHANGE(%)
	Elevation	*1965*	*1979*	*1983*	*1986*	*1965/1986*	*1983/1986*
Red spruce	790-1035m	7961	4429	1571	1967	-5997 (-75%)	+396 (+25%)
Balsam fir	850-1160m	25330	59666	27428	57381	+3205 (+126%)	+29953 (+109%)
White birch	790-1160m	4326	18963	4296	54519	+50193(+1160%)	+50223(+1160%)

Red Spruce and Balsam Fir Vigor

The percentage of red spruce in vigor class 1 decreased between 1979 and 1983 while those in the most heavily defoliated class (2) increased (Figure 2). A sharp reduction in the percentage of "healthy" (class 0) red spruce and increases in class 1 and 2 trees occurred between 1983 and 1986. Of eighty-one red spruce trees identified in the two most recent surveys, 38% declined in vigor, 58% remained the same and 4% increased. Changes were generally by one class level when they occurred.

Balsam fir trees showed a slight increase in vigor between 1979 and 1983 and a slight decrease in vigor between 1983 and 1986. No changes were evident in the most heavily defoliated (class 3) or in standing dead trees. Overall no consistent and significant changes in balsam fir vigor were detected between 1979 and 1986.

Regeneration

Large increases in seedling densities were observed between 1983 and 1986 for birch (white and/or yellow) and balsam fir (Table 2). Red spruce shows slight increases in seedling density since 1983, but remains very low compared to 1965. Birch seedling density appears to be directly related to increases in light intensity reaching the forest floor (Figure 3).

Discussion

Red spruce populations have undergone significant reductions in density and basal area throughout much of New England (Sicama *et al.* 1982; Scott *et al.* 1984; Vogelmann *et al.* 1985, 1988) and southward through the Appalachian mountain chain (Johnson and Siccama 1983). Canopy conditions are presently extremely open and heterogenous, with a large portion of dead standing trees. The loss of vigor and high mortality of red spruce in montane forest ecosystems appears to be continuing, and is accompanied by a variety of decline symptoms or characteristics.

Secondary shoots, variable types of yellowing of foliage, occasional short shoots and needles, and defoliation are all observed on damaged red spruce (Liedeker 1987). Winter injury occurs repeatedly in high-elevation red spruce (Friedland 1984, Evans 1987, personal observations), and contributes to apical dieback.

Balsam fir trees on the other hand are nearly completely asymptomatic, only infrequently exhibiting extensive defoliation or secondary shoot formation. Winter injury is not observed on balsam fir growing immediately adjacent to winter damaged red spruce trees. Why balsam fir saplings and trees have not responded rapidly to the reduced competition as red spruce succumbed is unknown. Possible effects related to secondary stresses such as wind (Klein and Perkins 1987) may explain why no symptoms are evident on balsam fir, yet we see reductions in density and basal area. Balsam fir (and spruce) trees on the edge of a gap are exposed to much higher natural and anthropogenic pollution stresses (Hagar and Kazda 1985, Harrington 1986, Marchand and Goulet 1986). Nevertheless, the balsam fir that remains standing is generally healthy. Most of the balsam fir mortality that does occur is through windthrow.

Balsam fir is experiencing heavy natural thinning in the upper coniferous elevations (1100-1160). This has resulted in the significant decrease in density, but not in basal area which has remained relatively constant. This also explains the decrease in the small balsam fir size classes (2-5 and 5-8 cm) and increases in the larger classes.

Essentially even-aged seedlings and young saplings of birch and balsam fir are thriving under the open canopy in gaps where red spruce mortality has been high. Natural competition will eventually vastly reduce their numbers, but they will probably re-establish a closed canopy within the next 30-50 years. Some red spruce seedlings are showing rather vigorous growth, while others show symptoms similar to those of the larger trees. The overall low red spruce regeneration suggests that this species may play a greatly reduced role in the next forest generation on Camels Hump.

Conclusions

Red spruce is continuing to experience a loss of crown vigor and is declining in all tree (≥ 2 cm d.b.h.) size classes. Winter damage occurs nearly every year, and is contributing to apical dieback and a general lack of vigor.

Balsam fir, while showing reductions in density and basal area, remains vigorous. Much of the current mortality of fir is probably due to secondary factors.

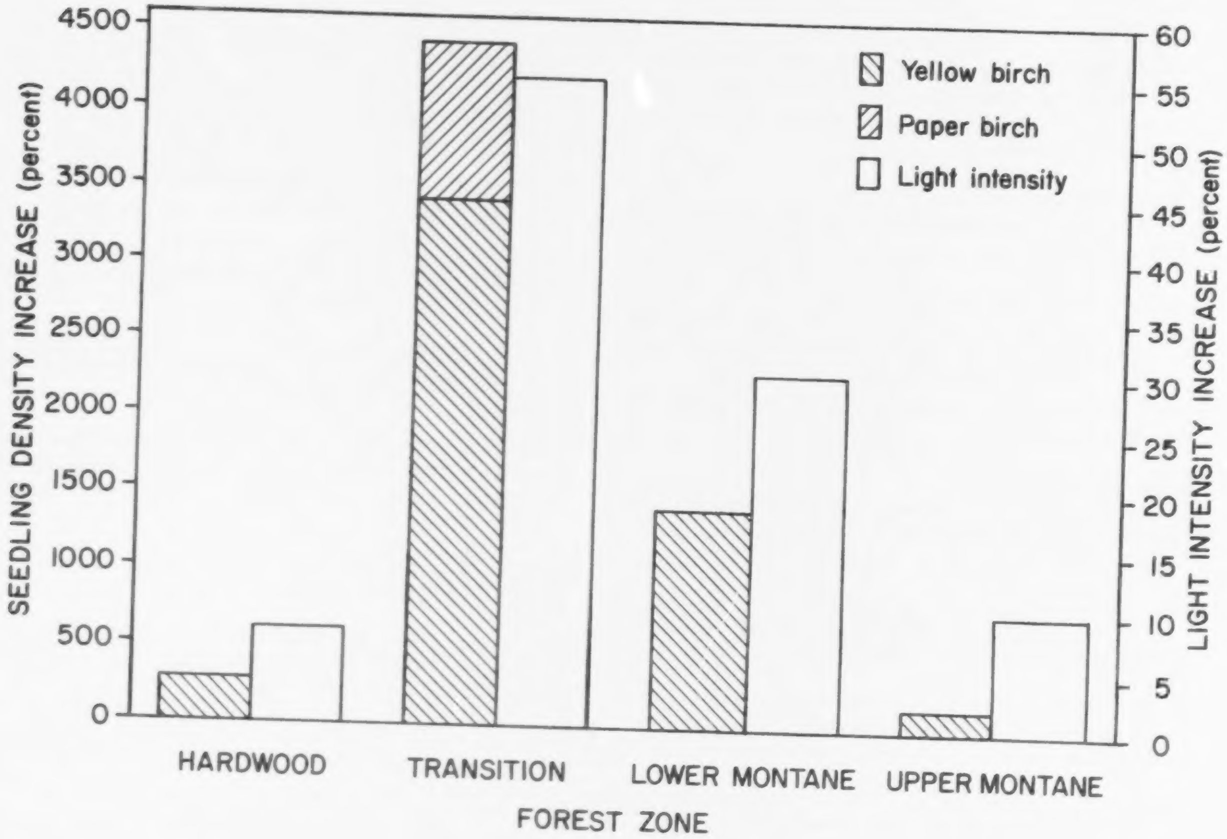

Figure 3.--Percent change in yellow and heart-leaved paper birch seedlings from 1965 to 1986 (left axis) and percent increase in light intensity from 1964/1965 (mean) to 1986 (right axis) as measured by photopolymerization of anthracene to dianthracene by major forest zone on Camels Hump, Vermont. The relative proportions are given for both species where their distributions overlap in the transition zone.

Healthy and vigorous regneration of birch and balsam fir is taking place in the understory and will probably form a closed canopy in the next generation. Red spruce may play only a minor role in this new generation.

Acknowledgments

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Regional Dendrochronologies of Red Spruce and Other Species in New England

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Abstract

Basal-area increments determined from thousands of cores from throughout New England show that growth of Picea rubens and Abies balsamea has decreased since the early 1960's, apparently as a consequence of forest aging. However, this age trend may not be related to growth decrease and mortality of Picea at high elevations. Eight other conifer and hardwood species do not show evidence of a growth decrease through 1980 that might be attributed to air pollution. Analysis of interannual variation in the growth of P. rubens shows effects of regional weather, especially winter temperature and temperature late in the previous growing season.

Introduction

Heavy mortality of red spruce, *Picea rubens* Sarg., has occurred in the past decade at high elevations in the mountains of the Northeastern United States. Environmental literature and the press have reported that air pollution is damaging and destroying the forests of the Northeast. Tree-ring analysis or dendrochronology provides one method for assessing forest decline that may have been induced by air pollution. This approach has been used both in Europe (e.g., Schweingruber et al. 1983) and in the United States (Cook et al. 1987). Since 1984 we have measured ring widths on thousands of trees throughout New England to determine whether or not widespread decreases in diameter growth are occurring.

From 1980 through 1985, the Forest Inventory and Analysis unit of the USDA Forest Service carried out an intensive inventory of New England forests, using thousands of randomly located plots. To estimate site index (height at 50 years), an increment core was taken at 1.4 m height from four dominant or codominant trees on each plot. As spruce decline became an important national issue, we decided that these increment cores could be used to determine the severity and extent of any growth decrease in *P. rubens* and in other important forest species.

Our approach to tree-ring analysis differs somewhat from standard dendrochronology. We prefer basal-area increment (annual increase in cross-sectional area at 1.4 m height) rather than radial increment (ring width) as a measure of growth. We have available only 1 to 4 individuals of any species on a given site; dendrochronologists usually use about 30. Therefore, we have chosen to average over all of the cored trees in a geographic "region": a region may be a state (e.g., Vermont), a part of a state, or two states taken together. Rather than removing age trend from each individual tree and averaging the indexes or detrended values for a year, we average the actual basal-area increments (or sometimes radial increments) over all trees of a species in the region.

Growth Decline in Red Spruce

We looked at *P. rubens* first because of the concern over heavy mortality of red spruce at high elevations. For this species, increment cores from special studies in the mountains of New Hampshire and New York were included with the forest inventory cores. Our first results (Hornbeck and Smith 1985) showed a regionwide decrease in both radial and basal-area increment in *P. rubens* in New England and the Adirondack Mountains (Fig. 1). Growth increased steadily until about 1960 and has decreased since then. At first these results appeared as important evidence for widespread spruce decline.

Although mortality is high in northeastern mountains (Johnson and Siccama 1984), we could see no evidence in our cores that the growth decrease was more severe at higher elevations (Hornbeck et al. 1986). Few of our cores were taken at an elevation greater than 1,000 m, whereas the most severe mortality seems to be located higher than this, that is, in the small fraction of the regional red spruce forest that is at the upper end of the elevational range for the species.

Analysis of our results using growth data reported for *P. rubens* by Meyer (1929) suggested strongly that the regional decrease in growth was a function of an aging forest (Federer and Hornbeck 1987). Meyer measured stand density and stand basal area on many second-growth red spruce stands in northern New England. From his summarized data by site index we calculated the expected mean radial and basal-area increments of individual trees as a function of age. The curves calculated from Meyer's data for an even-aged red spruce stand that was breast high (1.4 m) in 1915 closely match our regional growth curves (Fig. 1). Reduction of diameter growth in red spruce since 1960 is what would be expected in a forest that was regenerated around the turn of the century. Because of heavy logging and spruce budworm mortality, this seems to be what has happened. Seymour (1985) showed that 50 percent of Maine's red spruce forest is 50 to 80 years old. Another 20 percent is too young to have been sampled in our study. About 70 percent of our sampled trees are between 40 and 100 years old. We conclude that the growth decrease since 1960 in the vast majority of red spruce growing at low elevations probably is a consequence of an aging, second-growth forest.

Is the growth decrease more severe on some kinds of sites than on others? The Forest Service's Inventory and Analysis unit recorded many kinds of qualitative and quantitative data for each sampled plot. We conducted several kinds of multivariate analyses relating the change in growth rate to site and stand characteristics. We could not find evidence that the amount of growth decrease was related to any site variables.

Growth in Other Species

Diameter growth in cores from nine other important tree species in New England was measured for the same manner as for *P. rubens* (Hornbeck et al. 1987). Regional mean curves for balsam fir, *Abies balsamea* (L.) Mill, show an apparent leveling or decrease in growth since about 1965 (Fig. 2), somewhat later than *P. rubens*, with which it is associated. This may be the same age-related effect found for *P. rubens*. The reason for the slightly later response is not known.

All other coniferous (Fig. 2) and hardwood species (Fig. 3) that we have studied have regional mean curves with either constant or continuously increasing basal-area increment through 1980. Eastern white pine, *Pinus strobus* L., has an average growth rate nearly twice as high as that of other species (Fig. 2). It is particularly susceptible to ozone-induced injury (Woodman 1987), but we find no evidence that its growth is affected on a regional

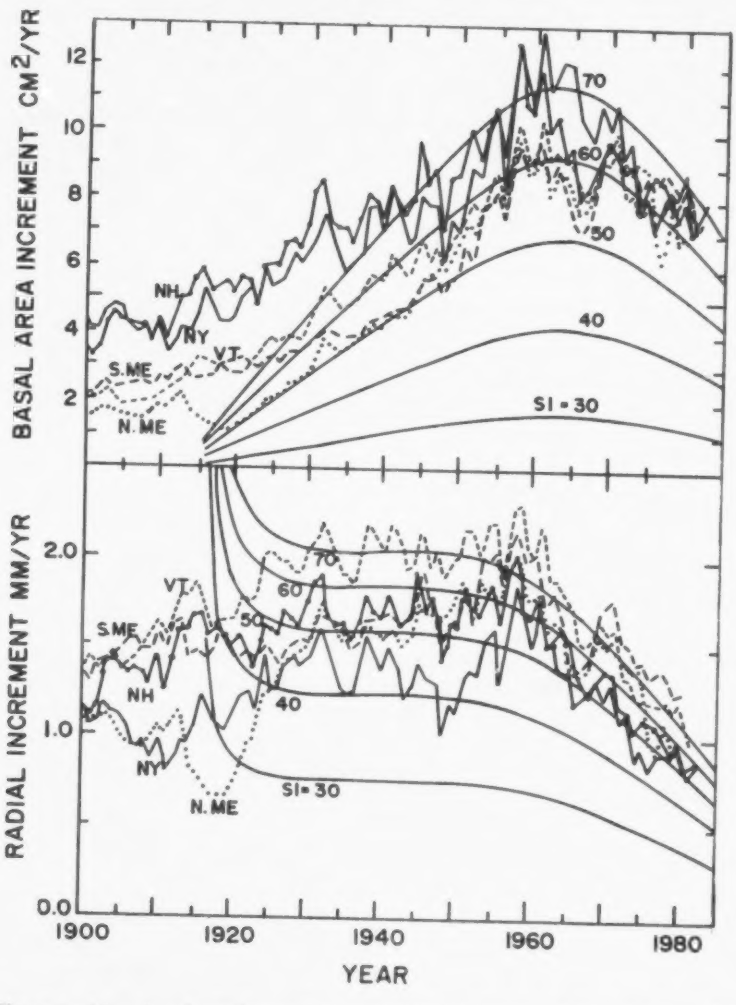

Figure 1.--Mean basal area increment (top) and radial increment (bottom) for red spruce in five geographic regions from 1900 through 1981, and curves predicted from Meyer's (1929) data for five site indices assuming an even-aged forest that reached 1.4 m height in 1915.

basis. Since 1980, sugar maple, *Acer saccharum* Marsh., appears to be suffering from an unexplained dieback, particularly in southern Quebec. We see no trace of this in our data, but the data end in 1980 (Fig. 3). In northern red oak, *Quercus rubra* L., some recent years of narrow rings, especially in Connecticut and Rhode Island, are attributable to gypsy moth defoliation (Fig. 3).

Much of the northern hardwood, central hardwood, and white pine forests of the region developed on abandoned agricultural land. This abandonment has been gradual over the last 150 years; some of the second-growth forest has been cut selectively or clearcut. These forests as a whole are uneven-aged, so an age-related growth decrease should not be expected.

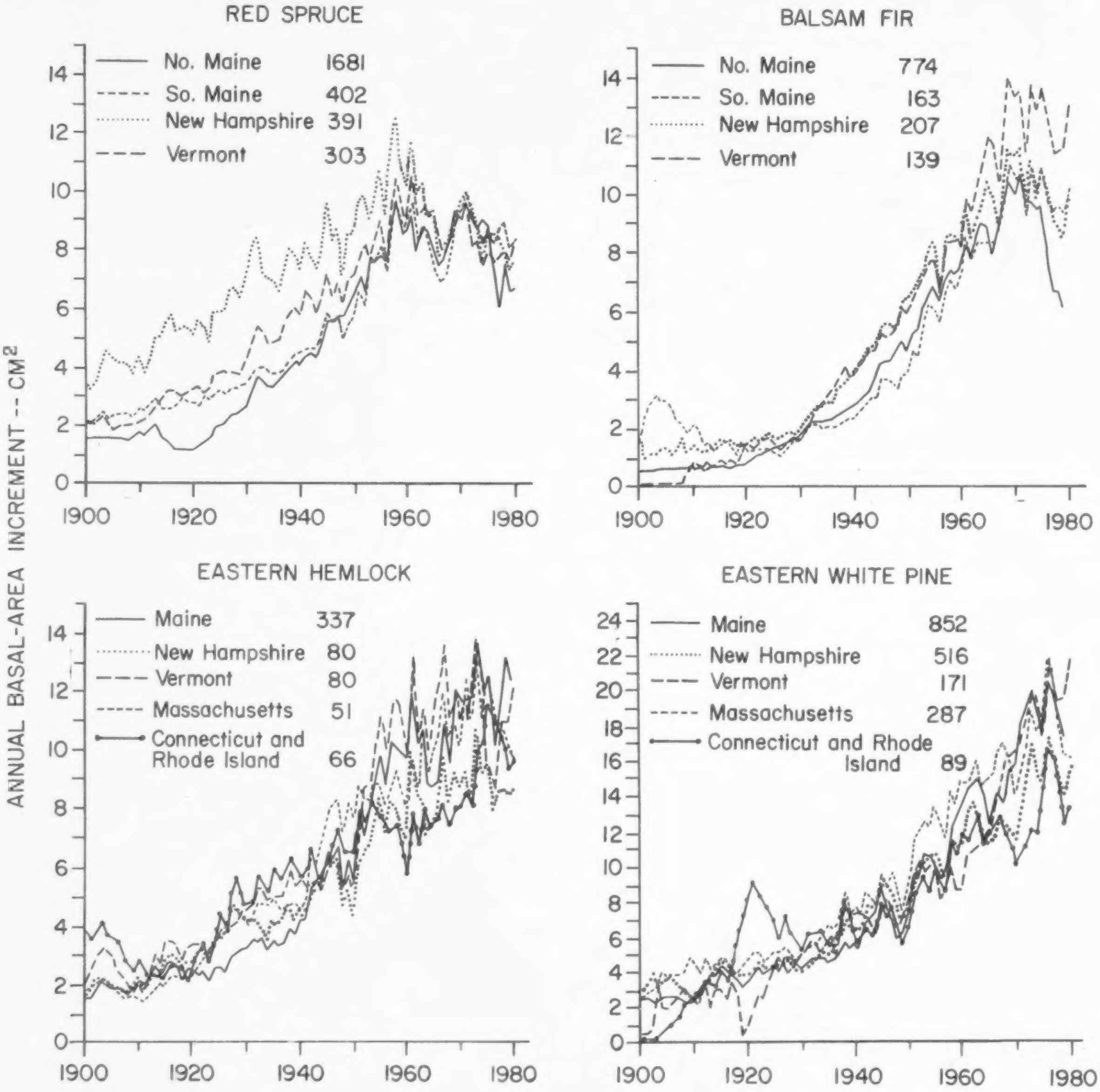

Figure 2.--Mean basal-area increment from 1900 through 1981 by geographic region for red spruce *(Picea rubens* Sarg.), balsam fir *(Abies balsamea* (L.) Mill), eastern hemlock *(Tsuga canadensis* L.), and eastern white pine *(Pinus strobus* L.).

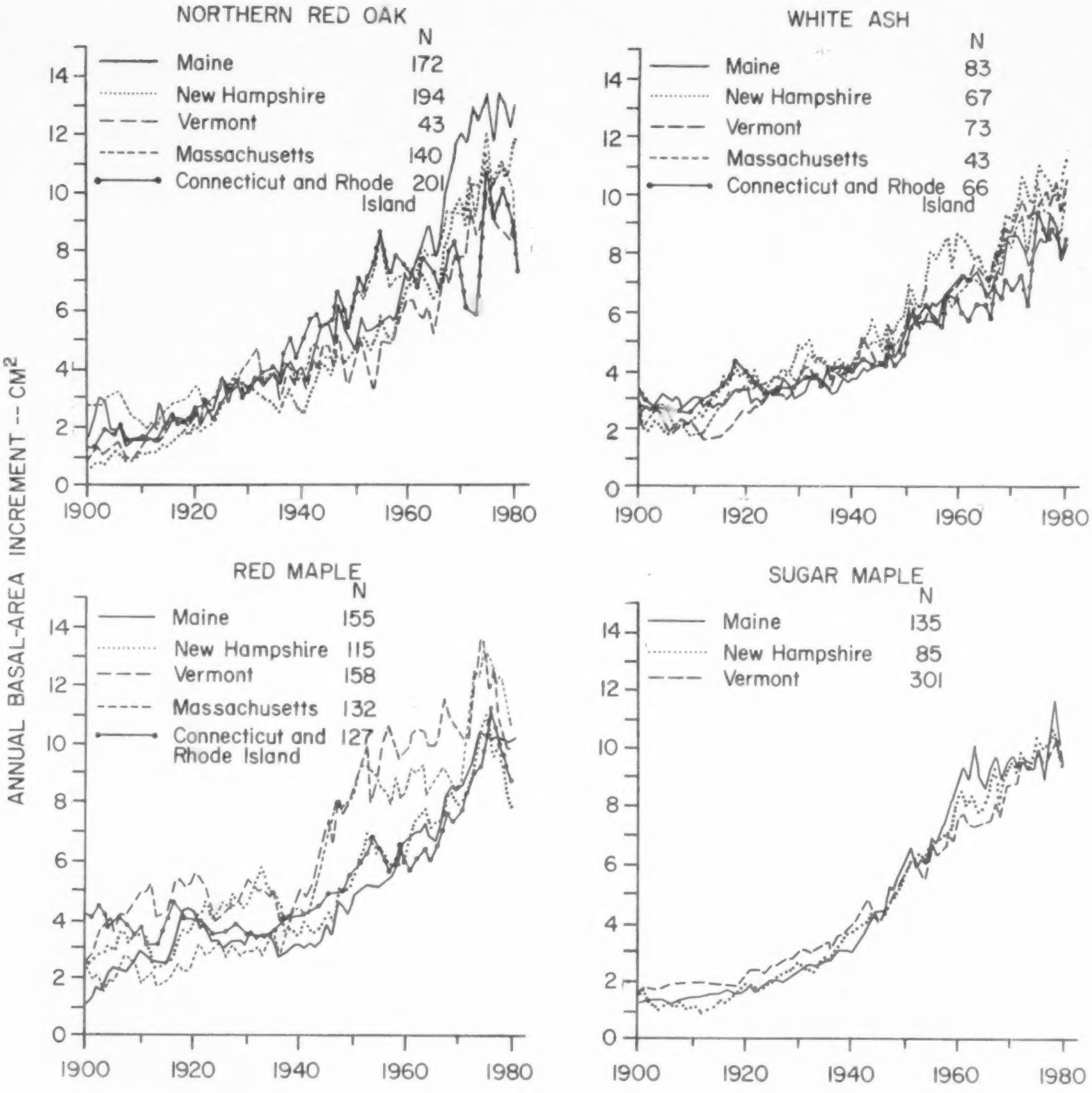

Figure 3.--Mean basal area increment from 1900 through 1981 by geographic region for northern red oak (*Quercus rubra* L.), white ash (*Fraxinus americana* L.), red maple (*Acer rubrum* L.), and sugar maple (*Acer saccharum* Marsh.).

Weather Effects on Red Spruce

In *P. rubens* and other species, some year-to-year variations in ring width tend to be similar among regions (Figs. 2-3). Synchronicity in wide and narrow rings over such a large geographic area probably is induced by year-to-year differences in weather patterns over the entire Northeastern United States; one might expect the interannual variation to be caused by warm or cold or wet or dry growing seasons. Surprisingly, this is not the case for *P. rubens*. Winter temperature and the temperature late in the previous growing season appear to have the most influence on ring width (Conkey 1979; Cook et al. 1987)). If these interactions of weather and ring width could be explained physiologically, the cause of high-elevation mortality might be found.

We have related three regional curves of basal-area increment to regional weather data using three multiple regression models of different levels of physiological sophistication (Federer et al. 1987). Age trend was removed from each series by indexing, or taking the ratio of the mean for a year to the value of a cubic smoothing spline through the series. Lag-one autocorrelation was then removed (prewhitening). Cross correlations among the resulting three series (Maine, New Hampshire-Vermont, Adirondacks) ranged from 0.54 to 0.84, suggesting strong interregional weather effects (Fig. 4). Daily maximum and minimum temperatures and daily precipitation were obtained for the same period by averaging data from five or six weather stations per region. Up to seven weather-related variables were defined a priori for each model, then dropped if they were not significant.

Model I, a standard dendroclimate response function, described 18 to 33 percent of the variation in the three regional series. Mean temperature of the previous July-August, mean temperature of the previous November-December-January, and mean September temperature of the current year were significant predictors. This validates the same results obtained by Conkey (1979) and Cook et al. (1987) for more localized sites and weather stations in the same geographic area. Model II used variables based on estimated daily soil-water deficits and on daily temperature integral above 6°C for the early and late parts of the current growing season and for the later part of the previous growing season. Model III variables included estimates of photosynthesis and respiration using nonlinear temperature responses for each season, with photosynthesis reduced by soil-water deficit. Despite their physiological basis, Models II and III described less than 18 percent of the interyear variance in any region. In all models, variables based on temperature in the latter part of the previous growing season and temperature in the winter were important, whereas variables based on temperature and water in the current growing season were not significant. However, much of the interregional correlation remains unexplained.

A long-term effort is underway to modify a physiologically based carbon-water model (Sollins et al. 1979) for red spruce. Hopefully, it will do a better job of integrating the various nonlinear weather effects on diameter growth. Cook et al. (1987) hypothesize that spruce mortality at high elevations has been caused by the cumulative effects of several kinds of extreme weather. This process should be amenable to study by such a physiological model.

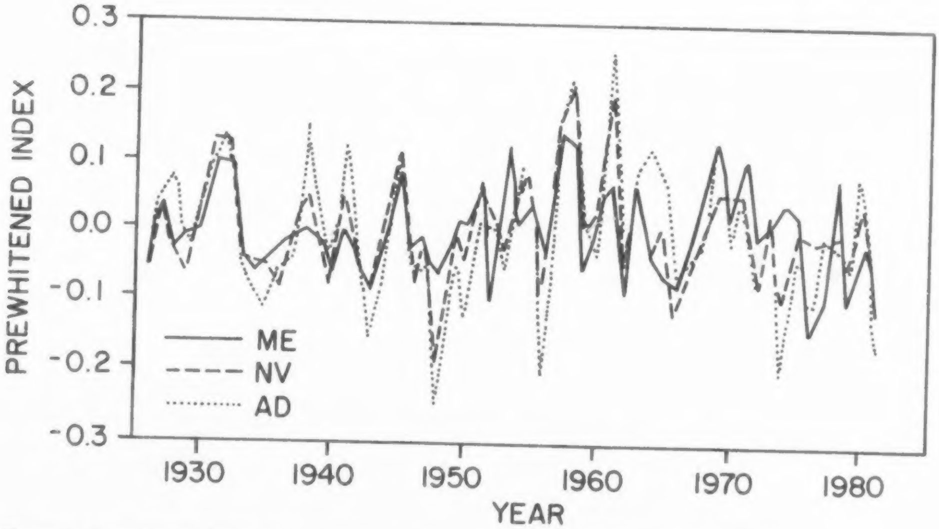

Figure 4.--Prewhitened index series of red spruce for three geographic regions: ME:Maine, NV:New Hampshire and Vermont, and AD:Adirondack Mountains.

Conclusions

A general decrease in diameter growth of *P. rubens* and *A. balsamea* throughout the northeast since the 1960's may be a natural effect of forest aging and is not related to site characteristics. However, high-elevation mortality probably is a separate phenomenon. Through 1980, no other important tree species in New England shows evidence of widespread growth decrease.

Temperatures in the previous growing season and during winter are more important to diameter growth in *P. rubens* than temperature and precipitation in the current growing season. The effects of regional weather on regional tree growth are not yet understood, but may be involved in the mortality of *P. rubens*.

Acknowledgements

Paul Krusic and Marianne Kenney prepared and read thousands of increment cores for this project. The research was supported by funds provided by the National Vegetation Survey Research Cooperative with the joint U.S. Environmental Protection Agency-USDA Forest Service Response Program. The Forest Response Program is part of the National Acid Precipitation Assessment Program. This paper has not been subject to EPA policy review and should not be construed to represent the policies of that Agency.

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Historical Growth Patterns of Red Spruce and Balsam Fir at Whiteface Mountain, New York

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Abstract

Dendroecological methods were used to characterize historical growth allocation of red spruce (Picea rubens Sarg.) and balsam fir (Abies balsamea (L.) Mill.) growing in stands at 900 and 1100 meters elevation at Whiteface Mountain, New York. Comparison of three vigor classes of dominant red spruce revealed sustained diminished growth at both elevations since the mid-1960's. Trees of "Good," "Intermediate," and "Poor" vigor exhibited similar growth patterns at both altitudes with "Poor" trees showing evidence of earliest decline. Growth of young co-dominant red spruce has also declined since 1965. In contrast balsam fir basal area increment exhibited age- and site-related differences and did not show a consistent growth decline pattern.

Introduction

Red spruce (*Picea rubens* Sarg.) is currently in a state of growth decline throughout much of its natural range in the United States, from the Great Smoky Mountains of North Carolina and Tennessee to the mountains of New York and New England (Johnson and Siccama 1983, Hornbeck and Smith 1985, Johnson and McLaughlin 1986, McLaughlin et al. 1987). Balsam fir (*Abies balsamea* (L.) Mill.), a common associate of red spruce in subalpine forests, reportedly does not show a similar consistent decline pattern (Johnson and McLaughlin 1986). While dendroecological and mensurational investigations have characterized changes in the growth of red spruce and balsam fir, detailed studies of the growth patterns of trees of differing vigor classes and age cohorts in declining stands have not been made. Such population studies are needed if the nature and extent of decline are to be understood. This study was undertaken to quantify specific changes in healthy and declining red spruce and balsam fir in stands at two elevations on the western slope of Whiteface Mountain, New York.

Methods

Selection of Sample Trees

Upon obtaining a permit to conduct research on New York State Forest Preserve lands, two study sites were established in spruce-fir forests, based on the following criteria: 1) no evidence of historical disturbance such as logging or fire; 2) absence of fir-wave phenomena; 3) reasonably accessible. Both study sites were located in a virgin area within the subalpine coniferous forest on the west slopes of Esther Mt., upslope from the Whiteface Mt. Memorial Highway, one at the lower limit of the spruce-fir forest (900m) with NW aspect, and one at the upper limit of red spruce (1100m) with W aspect.

All potential sample trees of red spruce on these 1-2 ha sites were located, classified into three vigor categories based on fullness of crown and amount of twig dieback and needle loss, ("Good," "Intermediate," and "Poor"), and a single increment core was taken from each. Recently dead trees comprised the bulk of the lowest vigor category ("Poor"). Thirty-six sample trees, 18 from each site, 6 for each vigor category, were selected from 190 trees in the preliminary survey for detailed growth analysis. Correlation analysis of the core data was used to select the trees in each vigor class that were most highly correlated with mean growth and other trees in that catetory. To compare the growth response of red spruce of younger age to older red spruce, we also sampled 5 young codominant red spruce at each site.

Within a 8m radius of each of the 36 red spruce sample trees, all living and recently dead overstory balsam fir were chosen for study. Total number of sample trees was 48 on the low site and 143 at the high site. For balsam fir, two increment cores taken at 1.4m height were used to measure growth.

Growth Analysis Procedures

Historical growth data for red spruce were derived by detailed stem analysis (Duff and Nolan 1953, LeBlanc et al. 1987a). This intensive procedure was used because it provides measurements of apical and cambial growth along the entire bole of the tree and allows comparison of growth parameters differentially affected by environmental factors. In May, 1985, sample trees were felled at ground level and cross-sectional disks were taken according to the following procedure. Starting at the apex, disks were taken from each internode (as identified by bud scale scars). When bud scales scars were no longer visible, disks were taken at 15 cm intervals down to the base of the stem. Disks were air dried, sanded, and the surface shaved smooth along 4 radii located on the cardinal compass bearings. Rings were counted on all disks and crossdating was performed between radii on each disk and between disks within each tree. Crossdating between trees on each site was also performed. Ring widths were measured on all disks taken from identifiable internodes near the apex to obtain detailed growth data for the most recent two decades, and ring widths were measured on every third disk from those that were taken at 15 cm intervals. Ring width measurements were made with a precision of ±0.01 mm using the Tree Ring Increment Measurement (TRIM) system (Fayle et al. 1983). Calculations and graphical analysis were accomplished using software developed by D.C. Fayle et al. of the Ontario Ministry of Natural Resources, Canada.

The following growth parameters were described for the period 1935-85: Specific Volume Increment (SVI), Ring Number Sequence (RNS), and Growth Layer Profile (GLP). SVI (mm) represents the mean radial growth over the entire length of the tree bole during a given year, measured as volume of wood produced (mm^3) per unit surface area of cambium (mm^2). This parameter reflects growth performance along the lower, branch-free bole, since this portion of the stem accounts for the majority of the stem length.

RNS (mm) represents the mean radial growth in the upper crown at a constant distance or position with respect to the apex of the stem. RNS's were derived from ring widths from 1-3 m from the apex.

Comparisons between SVI and RNS were made to assess where along the stem alterations in growth occurred. Growth along the lower bole is more affected by competition, changes in stem size, and carbohydrate and hormone gradients associated with tree age. Radial growth in the upper crown is less affected by these factors. RNS's are more sensitive to extrinsic factors that cause injury to stem or branch apices while SVI data better reflect tree responses to factors that limit overall primary production (LeBlanc et al. 1987a).

GLP (mm) is a graphical representation of mean radial growth along the entire length of the stem for a given year and provides an assessment of the nature and timing of growth alterations. GLP's were determined based on percent total height. In this report, selected GLP's are presented representing years of particularly poor growth at the study sites.

Growth of balsam fir was determined by measuring increment core ring widths using the TRIM system. Basal area increments were calculated from ring widths and then summed over five year periods to remove short-term variation.

Results and Discussion

Red Spruce Growth

Graphs of the Ring Number Sequences for each vigor class group at both elevations indicate that all trees exhibited approximately coincident decreases in growth during the period 1965-1985 (Fig. 1). Abrupt alterations in growth occurred in the mid-1960's and 1970's. Prior to 1965, there was a nearly constant mean growth level for all trees except those of the "Poor" vigor category which began to decline in the mid-1950's. Specific Volume Increment generally paralleled RNS (Fig. 1). Mean age near butt level of the dominant red spruce was 254.9 ± 54.6 yr. at 900 m (range, 164-319 yr.) and 216.8 ± 62 yr. at 1100 m (range, 106-293 yr.). Mean age of the young red spruce was 106.6 ± 13.5 yr. and 115.6 ± 17.0 yr. at the low and high sites respectively.

The young low site trees exhibited a long-term increasing growth trend from 1935-64, probably associated with release from overstory suppression (Fig. 2). Growth reduction was marked in 1965 followed by several years of recovery before a declining growth trend was observed during the mid to late 1970's. High site young red spruce showed a downward growth trend beginning about 1955, a response similar to that observed for the high site "Poor" dominant trees (Fig. 2). The SVI pattern closely followed that of RNS (Fig. 2). Long-term growth potential alteration in both dominant and younger codominant red spruce may have resulted from injury to apical meristems limiting repair of damaged tissue which, in turn, prevented or delayed recovery after severe climatic events. Effects of injury to a specific needle class could have a long carry-over effect since red spruce retains its needles for as long as 10 years.

Mean Growth Layer Profiles for selected years in which severe growth reduction occurred or for which long-term growth reduction trends began are presented in Fig. 3 and 4. Large decreases in ring width along the entire bole occurred in 1956 in all species and site groups except low elevation young red spruce where smaller decreases in ring width, mainly along the lower stem occurred (Fig. 4). In 1962, ring width decreased along the lower 90% of the bole in all site-age-vigor categories. Growth decrease of older red spruce trees began all along the stem in 1965 and continued in 1966. Upper stem decreases were larger than lower. Radial growth of both young and older trees decreased sharply in 1974, especially along the upper stem. By this time trees in the "Poor" and "Intermediate" categories were growing very little. These trees were scarcely able to respond to extrinsic environmental conditions because of their severe decline state. As a result, yearly variation in growth in both young and older trees was minimal after this time.

The mid 1960's growth decline of red spruce coincided with severe regional drought (Cook and Jacoby 1977, LeBlanc et al. 1987b), while decline during 1974-84 coincided with a period of abnormal winter temperatures (Karl et al. 1984, LeBlanc et al. 1988). A comparison of the growth of red spruce at Whiteface Mountain with plantation-grown conifers (red pine (*Pinus resinosa* Ait.) and Norway spruce (*Picea abies* (L.) Karst.) in the southeastern Adirondacks at Pack Forest indicates that varying growth patterns are well correlated with climate (LeBlanc et al. 1988). Coincident periods of decreased growth without high year-to-year correlation in growth reduction suggest that different species were affected by regional climatic phenomenon with varying degrees of sensitivity.

Balsam Fir Growth

Unlike red spruce, balsam fir showed no consistent growth decline pattern across both elevations. Mean five year basal area increment at the low elevation site was generally less than that at high elevation prior to 1950 (Fig. 5). In each age cohort (1874-1920, n = 10 and 80 for low and high sites respectively; 1921-1930, (n = 10 and 38); 1931-1938 (n = 15 and 14); 1939-1952, (n = 13 and 11), basal area increment steadily increased at the low site and by 1960 exceeded that at higher elevation. Accelerated growth at the low site may have resulted from competition release after tree blowdown caused by the 1950 hurricane. Apparently the upper site was less influenced by that storm, since an increased growth trend of balsam fir was not observed there.

Upper elevation trees showed reduced basal area increment following 1965 but the growth reduction was age-related. Reduced growth of trees of older cohorts (1874-1920; 1921-30) (Fig. 5A, B) was greater than that of younger trees; reduction in younger cohorts (1931-38 and 1939-52) was slight (Fig. 5 C, D). Growth reduction response of balsam fir measured at the high site did not occur at the low site. Hornbeck et al. (1986) also reported age- and size- dependent variation in basal area increment of balsam fir in Maine during this period.

The role of air pollutants in growth decline should be carefully considered. If air pollutant concentrations or depositions are positively correlated with climate variables, it is inappropriate to conclude that air pollutants do not affect tree growth even when growth-climate correlations are very high. Whether higher inputs of atmospheric pollutants to subalpine forests (Lovett et al. 1982) than at lower elevation influence the more severe decline of red spruce at Whiteface Mountain is uncertain. However, the concomitant occurrence of greater environmental severity at high altitude and higher pollutant loadings make determination of the role of atmospheric pollutants on three growth difficult.

Acknowledgments

This research was supported by the U.S. Department of Agriculture McIntire-Stennis Program and the Cooperative State Research Service Special Research Grants Program, the New York State Energy Research and Development Authority, the Emprie State Electric Energy Research Cooperation, and the Electric Power Research Institute. We are grateful to Karen Worden for competent technical assistance.

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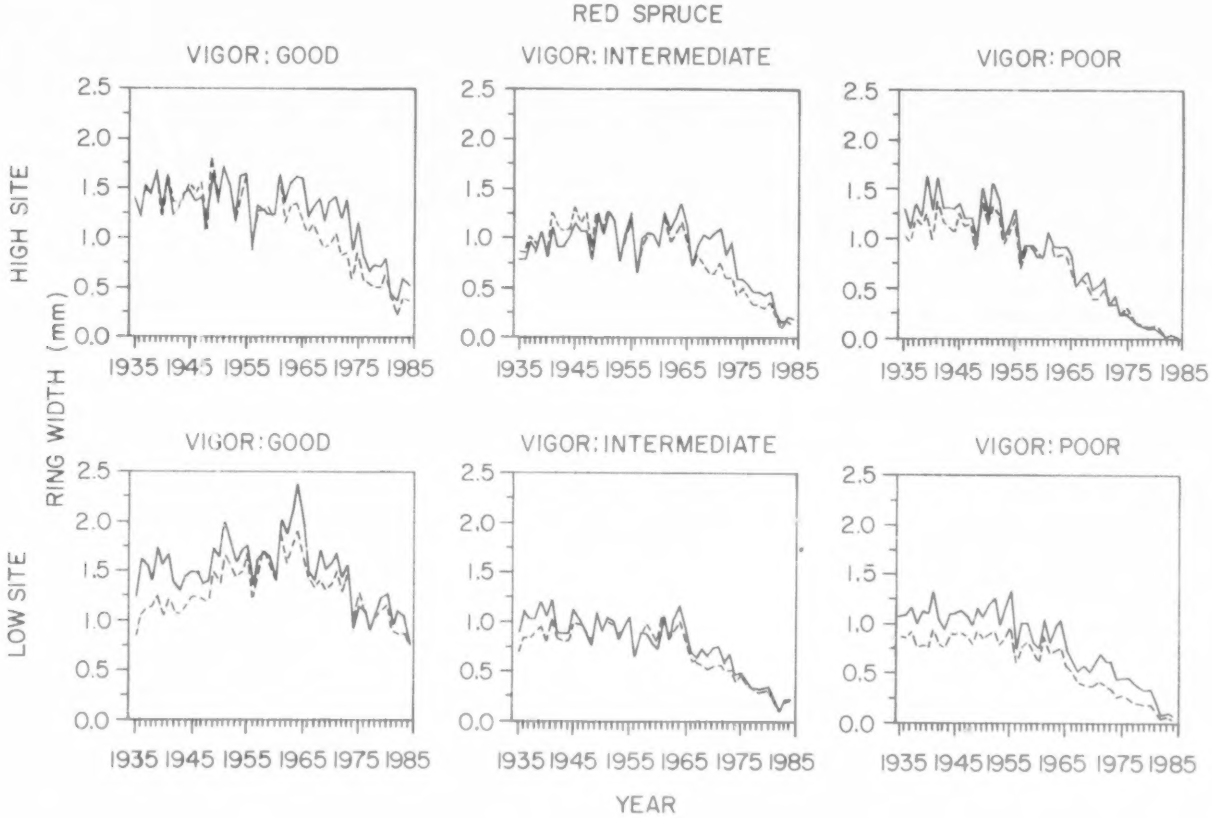

Figure 1.--Mean ring number sequence (solid line) and mean specific volume increment (dashed line) for red spruce of three vigor classes: "Good", "Intermediate," and "Poor" at 900m ("Low Site") and 1100 m ("High Site") at Whiteface Mountain.

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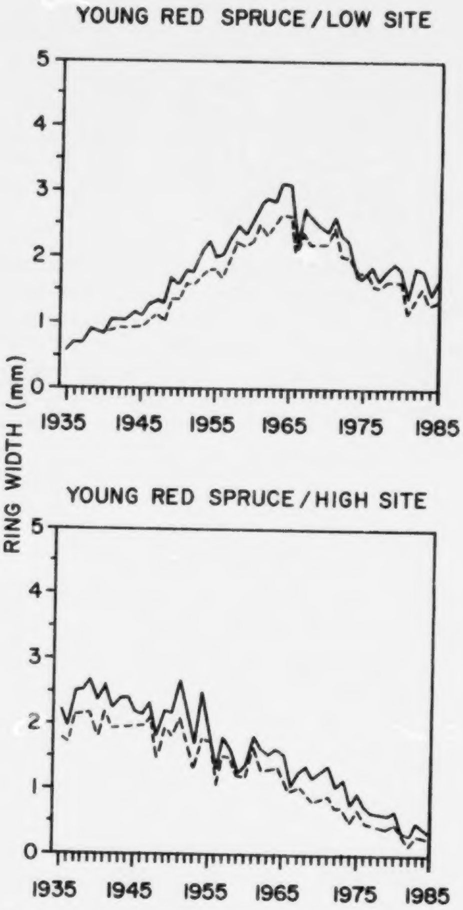

Figure 2.--Mean ring number sequence (solid line) and mean specific volume increment (dashed line) for young red spruce at 900m ("Low Site") and 1100m ("High Site") at Whiteface Mountain.

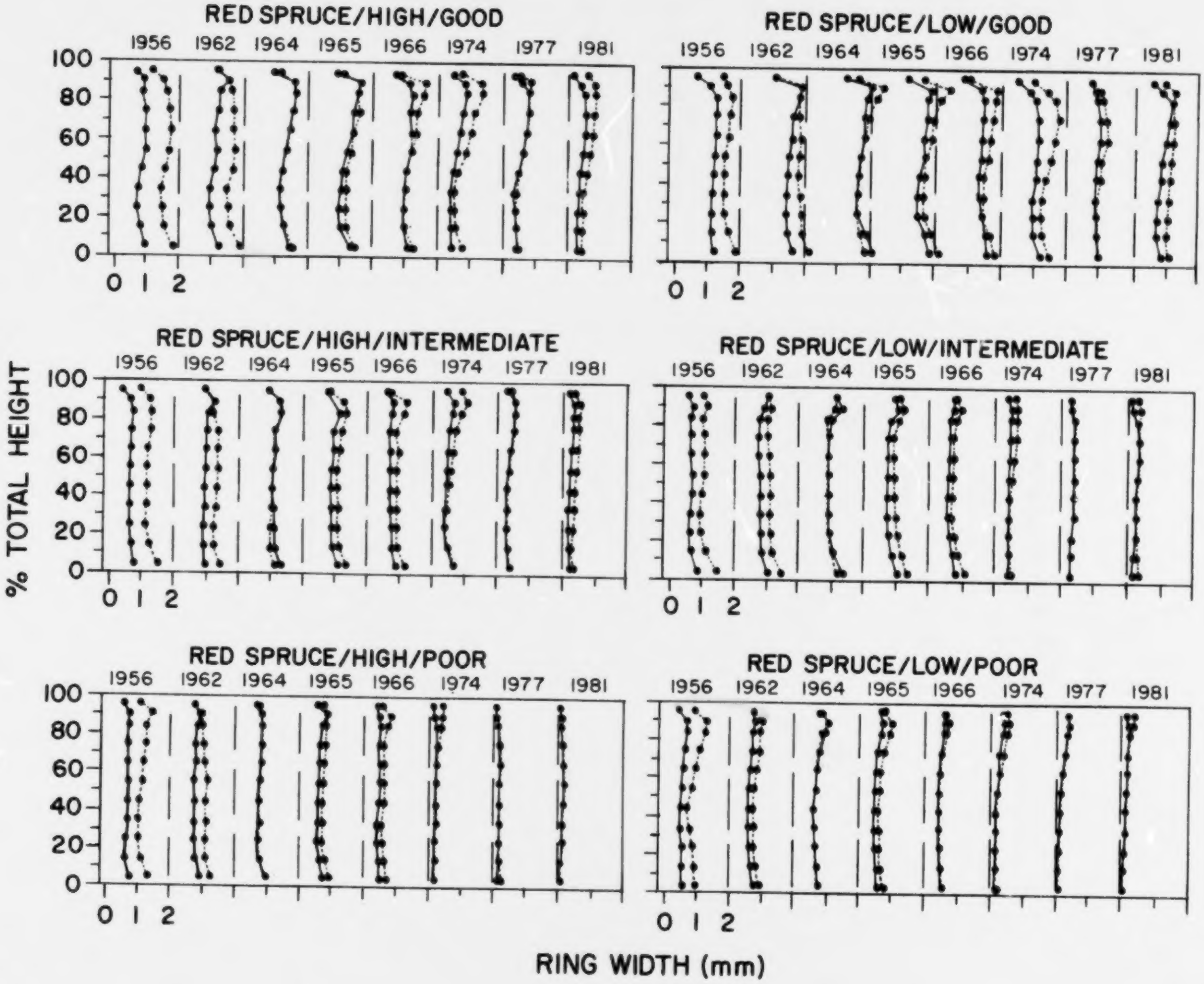

Figure 3.--Mean growth layer profiles for red spruce of three vigor classes "Good," "Intermediate," and "Poor" at 900m ("Low") and 1100m ("High") at Whiteface Mountain. The solid line represents the profile in mm expressed in relation to percent total tree height for the year above the panel. The dashed line represents the profile for the previous year and serves as a reference for assessing the degree and position of ring width change.

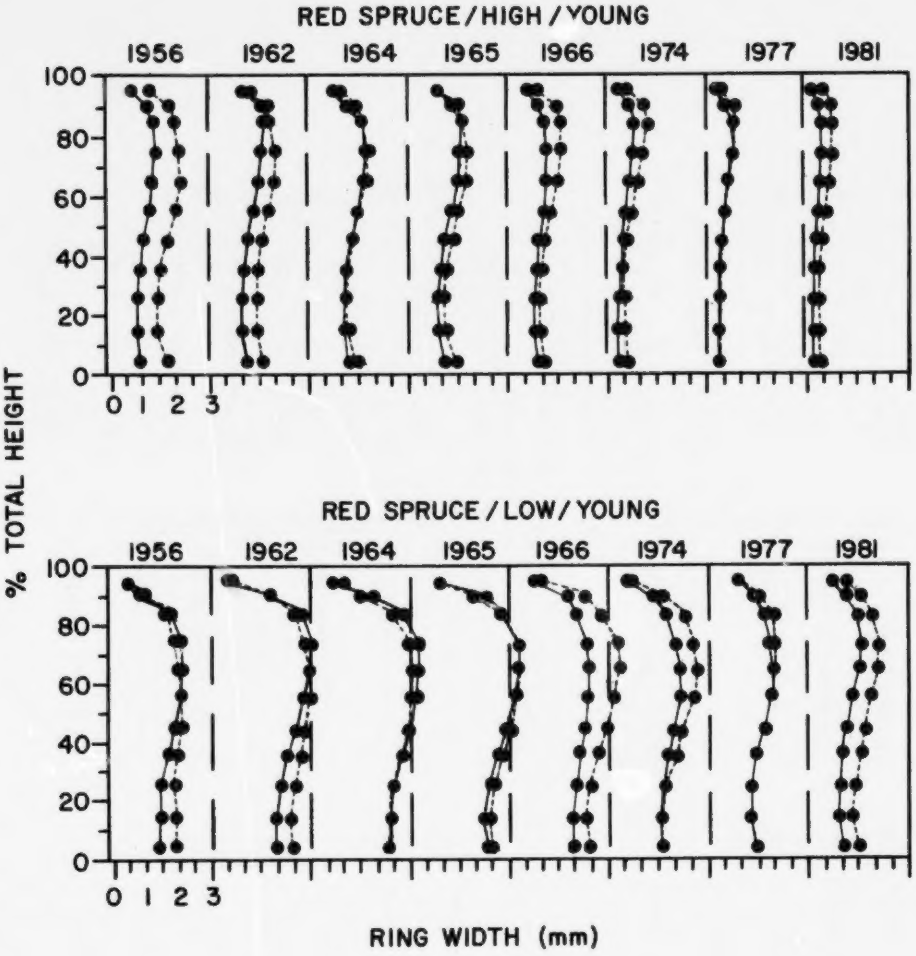

Figure 4.--Mean growth layer profiles for young red spruce at 900m ("Low") and 1100m ("High") at Whiteface Mountain. The solid line represents the profile in mm expressed in relation to percent total tree height for the year indicated above the panel. The dashed line represents the profile for the previous year and serves as a reference for assessing the degree and position of ring width change.

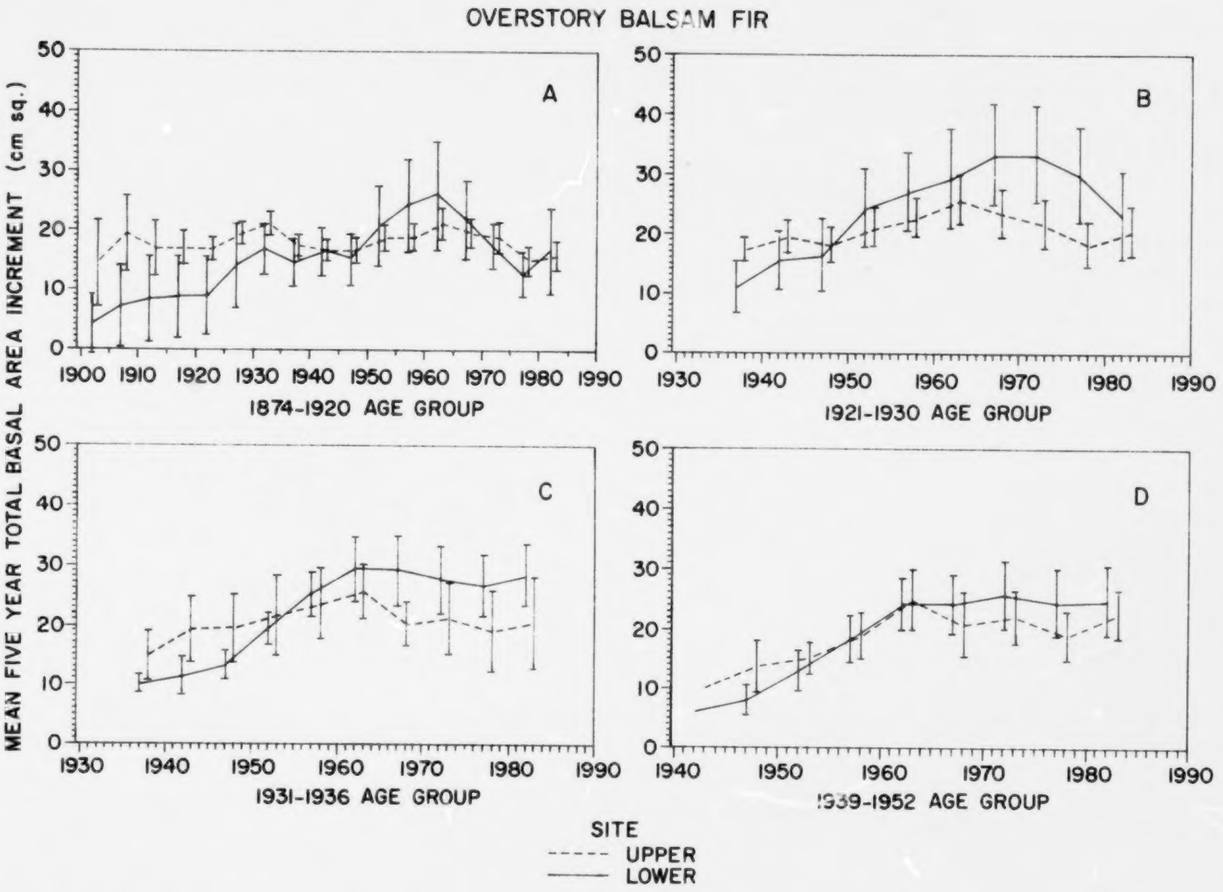

Figure 5.--Mean five-year basal area increment (cm²) of balsam fir cohorts at Whiteface Mountain: A, 1874-1920; B, 1921-1930; C, 1931-1938; D, 1939-1952. Vertical bars represent 2 standard errors of the mean.

Tree Rings, Climate, and Red Spruce Decline

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Abstract

We determined the relationship between standardized tree-ring widths and monthly climate data for calibration and verification periods from 1850 to 1981 and found that after 1960, there was a distinct shift in the temperature variables related to standarized ring widths. Regression models suggested that from 1850 to 1960, warm Augusts and cold Decembers in the year prior to ring formation were associated with less than expected growth, and historical records of spruce mortality (unrelated to spruce budworm) showed that spruce died over extensive areas following periods of unfavorable August or December temperatures. The beginning of widely reported red spruce mortality in the early 1960's coincides with 1/ the beginning of the ring width decline, 2/ the change in the climate-ring width relationship, and 3/ several consecutive years of severe, regionwide winter damage in high elevation red spruce. The temporal correspondence of those several factors suggests that repeated and severe winter damage triggered the current episode of spruce decline.

Introduction

Hertel et al. (1987) reported that a consensus of scientists who have or are currently studying spruce decline indicated that in the northern Appalachians and Adirondack Mountains, a high degree of mortality and reduction in growth has occurred above about 900 m which is not readily explained by current models of usual stand dynamics and forest growth. At present, there is no consensus regarding the cause or causes of these phenomena.

Several observations led us to speculate that climate stress, particularly winter damage or drought might be involved in the spruce decline (Johnson and Siccama, 1983, Friedland et al. 1984, Cook, 1987, Johnson and McLaughlin, 1986). Climate stress in the form of drought or frost (freezing) injury has been considered a cause of other declines in the Northeast (Weiss and Rizzo 1987, Manion 1981) and climate stress has long been regarded as a likely contributor to forest diseases. Hepting (1963) discussed some of the indirect ways in which climate change (such as long-term warming) can alter important life-supporting factors in a forest and lead to disease, but except in the case of severe climatic events, rigorous proof of climatic influence on mature trees is very difficult given our current experimental capabilities. Johnson et al. (1986, 1988) used a combination of empirical studies to infer climate involvement in spruce decline. The steps in that analysis are explained below.

Important Characteristics of Tree-Ring Series

The current episode of high elevation spruce mortality is accompanied by a pronounced reduction in ring width of the remaining vigorous dominant and codominant trees which lasted at least 20 years and was unreversed as of the mid-1980's (Johnson and Siccama 1983, Johnson and McLaughlin 1986, Hertel et al. 1987).

Figure 1 shows that the reduction in tree ring width occurred at the same time (around 1960 or so) in stands of widely different disturbance histories. Five or six of the stands show a dramatic release in the period 1885-1910 as a result of logging (probably), whereas the majority show no signs of major disturbance back to 1850.

The disturbance histories and age structure (see Johnson and McLaughlin, 1986 for age data) of the high elevation forests studies by Johnson et al. (1988) make then distinctly different from those studied by Federer and Hornbeck (1987) and Meyer (1929). Federer and Hornbeck (1987) suggest that the decrease in growth they observed in mostly lower elevation spruce fit the expected patterns for pure, highly even-aged stands of second growth red spruce, reported by Meyer (1929) and suggest that spruce in the lower elevation forests are behaving as if in even-aged stands which reached breast height about 1915. Their application of Meyer's growth curves may be reasonable for stands which had been cut at the turn of the century, a major period of logging in the Northeast.

Red spruce reported on below reach breast height on average in about 1850 (with a wide range of variation --50 to 200 years) in multi-aged stands known to be uncut and unburned, as well as in other stands known to have been logged at the end of the last century (figure 1). The stands are very different from each other and far more heterogeneous and much older than the highly even-aged, old-field stands described by Meyer (1929), yet the downturn in ringwidth is essentially perfectly synchronized.

The data of Conkey (1984) suggest that after major disturbances, ring width in dominant and codominant red spruce in uneven-aged, high-elevation stands increases dramatically within a few years, then decreases gradually and fluctuates around a constant mean value for well over a century, or until the next major disturbance. Personal observations suggest that the prolonged period of constant ring-width might result from the fact that spruce tend to be considerably taller than the co-occurring fir or birch and often form a supercanopy.

Overall, then, we see no theoretical or empirical basis for applying

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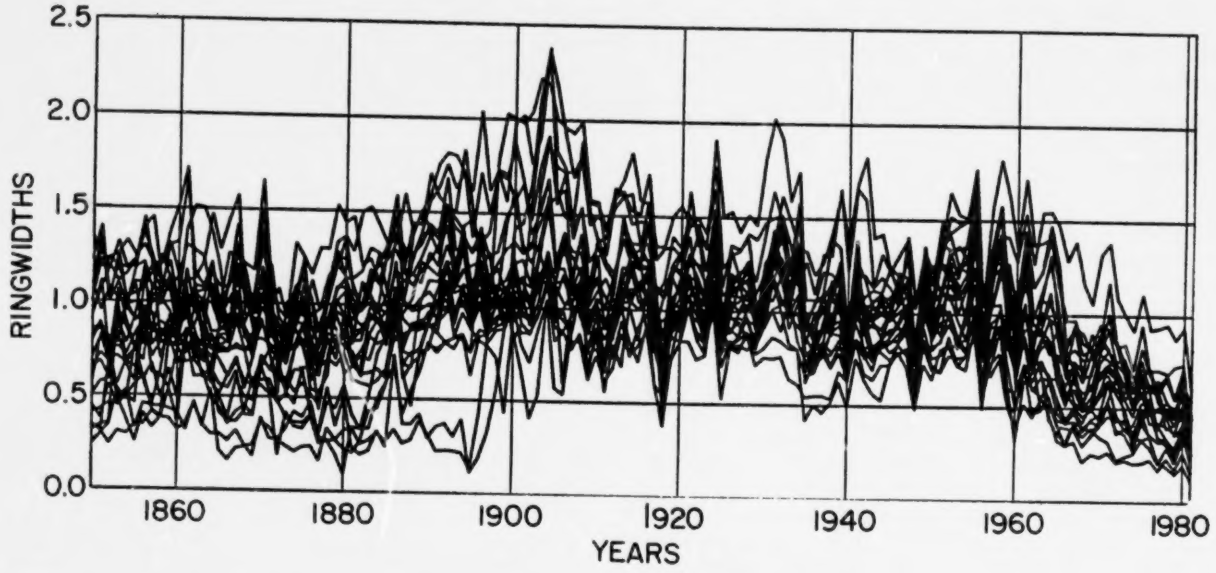

Figure 1.--Red spruce ring widths for 25 stands over 800 m elevation in New York and New England. Each line represents a stand (ring widths from 15-20 trees pooled). The values on the y-axis are normalized to the mean.

Meyer's (1929) data to the high elevation forests and contrary to the impression given by Zedaker et al. (1986), a simultaneous decrease in ring width across the sites studied is unexpected. We see no justification for applying an even-age, second-growth model to uncut patchwork forests which have a very wide variety of age classes and many trees over 250 years old. Related arguments are presented by McLaughlin et al. (1987).

Whether or not there has been a ring width decline and what it might be due to has been a controversial matter, but interestingly, it makes no difference to the case presented below what the ring width decline is due to (or even whether or not it exists). Other characteristics of the tree ring series show clear evidence of unusual behavior after 1960.

Methods

For the analysis carried out by Johnson et al. (1988), two cores per tree were cross-dated and measured at Oak Ridge National Laboratory (McLaughlin et al. 1987). The cross dating was then checked using a quality control program and the data analyzed using rigorous statistical methods explained in detail elsewhere (Fritts 1976, Cook 1987, Cook et al. 1987).

The procedures were designed to search for relationships between average monthly temperatures and the high-frequency variation in ring-width series as shown in figure 2. The ring-width series for each tree was standardized (Fritts, 1976) by removing all low-and intermediate-frequency variation (including the controversial ring width decline after 1960) using a tight-fitting smoothing spline (Cook and Peters 1981, figure 2a) and then removing the autoregressive (AR) persistence of each series using the appropriate first, second or third-order AR model (e.g. prewhitening; Box and Jenkins 1970, Cook, 1987). The resulting standardized values or tree-ring indices (observed value/spline value) minus the AR persistence were averaged to produce a stand-level tree-ring chronology that represents the high-frequency variation which exists at each site (figure 2b). The sample sizes ranged from approximately 25 to 40 series.

Previous tree-ring studies (Conkey 1979, Cook 1987) showed that ring width variations in high-elevation red spruce were associated with temperature rather than with rainfall so stepwise regression analysis was used to test for association between a subset of monthly temperatures and the indexed tree ring chronology at each site. For each site, a temperature-based model was calibrated using standardized ring widths for the period 1885-1940 as the predictand variable and average monthly temperatures from the Northern Plateau (NY) or New Hampshire Climatic Divisions as the independent or predictor variables. Each regression model was then used to predict standardized ring widths for three time periods not used in deriving the model. These model verification periods were: 1856-1884; 1941-1960; and 1961-1981. The first period (1856-1884) was a time when red spruce were declining across New England (see below). The second period (1941-1960) predates the current period of spruce decline, and thus should not be influenced by changes in the predictive capability of the models due to decline. Correlation coefficients for predicted vs. observed standardized ring widths and the reduction of error

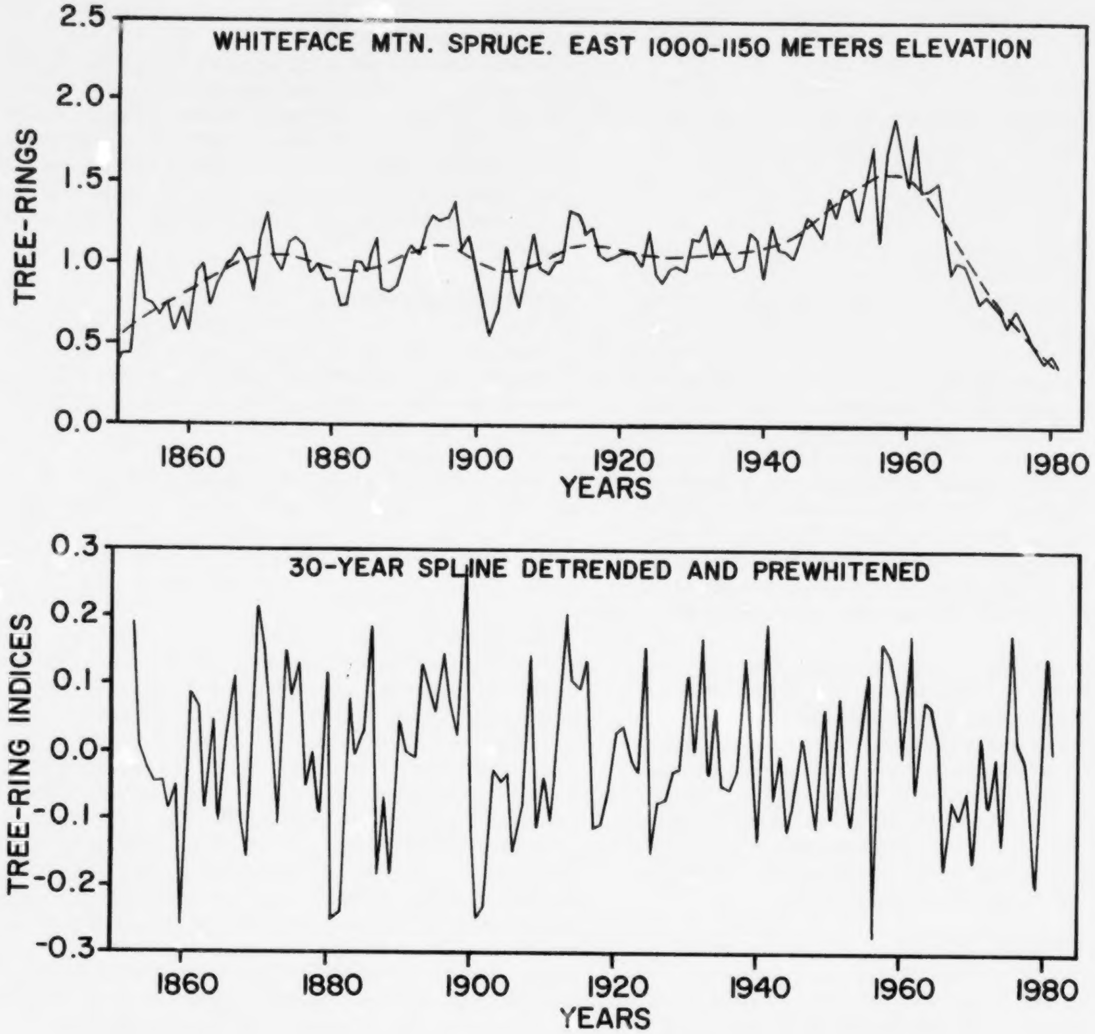

Figure 2.--Analysis of high frequency variation in detrended ring-width series. a. Smoothing spline fitted to raw ring-width series for standardization b. Standardized ring-width chronology (actual ring width for a given year divided by the spline value for that year) which has been prewhitened (autoregression removed). The standardized values are used in regression analyses as described in the text and by Cook et al., 1987).

statistic (Fritts 1976) were used to determine the effectiveness of the temperature-based models as predictors of standardized ring widths at each site.

Results of Tree-Ring Analyses

The results (Table 1) are consistent for the 14 middle-elevation transition forests (800-950m) and higher-elevation (1000-11500m) boreal stands regardless of age distribution and disturbance history. In the calibration period (1885-1940), August or July temperatures of the year preceding ring formation enter the model in 12 of 14 cases (negative correlation). December or January temperatures in the winter prior to ring formation enter the model in 12 of 14 cases (positive correlation). Winter temperatures are not highly correlated with summer temperatures ($|r| < .10$), and summer and winter months usually entered the regression equations with approximately equal standardized regression coefficients.

The results for the lower elevation sites are more variable, with average temperatures of different months related to the standardized ring widths, and with the model performance variable in the verification periods.

In 7 of the 10 high-elevation cases for which there are climate data, the models verify ($P < .10$) for the 1856 - 1884 period, even though 1870-1885 was a period of particularly high red spruce mortality throughout the Adirondacks and northern New England (Hopkins 1901). It was estimated that approximately half of the mature spruce in the Adirondacks died between 1870 and 1890 (Seventh Report of the Forest Commission, Albany, NY 1891). It is interesting that at high elevation, the cohort surviving until 1982 generally responded to climate in a predictable manner through the decline of the late 1800's. This could be due to the introduction of new factors in the recent decline or to the bias inherent in using the survivors of the 1870-1885 decline. If stands had been sampled in 1880, for example, perhaps the relationship between tree-ring width and climate would have been altered due to the inclusion of trees which may have eventually died.

Also of interest in this regard is a low elevation, old-growth stand (Keene Valley, table 1) which was cored by Cook in 1977 and which was included because of its regional relevance. Spruce were observed to be declining in the forests around Keene Valley in the 1870's and 1880's (Hopkins 1901). This low elevation stand shows that the standardized ring widths are not accurately predicted by the 1885-1940-based climate model for the period of regionwide decline, but are predicted for 1961-1976 (Table 1). This suggest that the loss of a "climate signal" may not be permanent if the trees survive a decline period.

Particularly striking in the mid- and high-elevation stands is the uniform ability of the temperature-based models to predict ring width from 1941-1960 but not from 1961-1981. This is in contrast to the behavior of the same trees during the decline period of the 1870's and 1880's, and represents a real departure from the long-term behavior of the trees rather than an artifact of the analysis. Examination of the climate-predicted and observed standardized ring widths (figure 3) indicates that the lack of fit occurs through the 1960's and into the 1970's when the August-December model fails to predict even the direction of change from year to year.

Figure 4 shows that there is an abrupt shift in the early 1960's when neither August nor December is strongly correlated with ring width, but November (year prior to ring formation) and current July temperatures are. Several factors appear to contribute to the patterns observed in figure 4, most important is the breakdown in the association between ring width and previous August (or July) temperature. This accounts for most of the lack of fit between modeled and actual standardized ring widths from about 1962 to 1974. From the 7-year running correlations, it is not possible to pinpoint an exact year when the climate-ring width relationship changes, and it appears that this may vary slightly across the sites of table 1. Most sites seem to change between 1960 and 1965, whereas the high elevation Adirondack sites appear to model well until 1966 or 1967 (e.g., Cook, 1987). Interestingly, the years 1977 to 1981 are predicted reasonably well by the August-December model, perhaps a suggestion that the trees have assumed a "normal" response to climate after a period of shock.

Temporal Relationships

The changes in tree-ring-climate relationships suggest that during the 1960's and 1970's, spruce were subject to stress severe enough to alter the physiology of most mature trees. As shown below, this was also a time of widespread red spruce death. Historical reports of spruce mortality dating back to 1962, indicate that many high-elevation spruce were dying during this period. Given the unfavorable effect of warm Augusts and cold Decembers on ring width, long-term climate records were analyzed to see if there was an association between anomalies or trends in those climatic factors during recent and past episodes of spruce mortality or injury.

While it is not known how warm late summers and cold early winters contribute to small rings, or how anomalies in those parameters might lead to mortality, the historical evidence suggests a connection. Episodes of severe and extensive red spruce mortality tend to occur during or shortly after periods characterized by warm late summers and/or cold early winters. Using climate records from the Northern Plateau Climatic Division (NY), reviews of episodes of red spruce mortality and historical materials (Figure 5, Johnson et al., 1986) the temporal correspondence between periods of unfavorable climate and periods of spruce mortality was examined. Figure 6 is a representation of favorable and unfavorable climate for red spruce, based on long-term climate patterns in the Northern Plateau Climatic Division (NY). The periods of stress simulated on figure 6 (positive index values) are based on the occurrence of December or August temperatures occurring 5% of the time or less with the magnitude of the stress simulated by the standard normal deviate (Z-score).

Since red spruce tree-ring series show distinct persistence, the carry over effect in figure 6 of favorable and unfavorable years was simulated with the AR models which were used to remove autocorrelation for the analysis of high-frequency variance. The resulting stress indices reflect the persistence inherent in the tree-ring series and illustrate the way in which red spruce may carry over the effects of favorable and unfavorable weather into succeeding years. Notably, the higher elevation trees showed a greater degree of persistence in the tree ring series compared to the lower elevation trees.

In this representation of climate stress, the most pronounced periods of unfavorable temperatures occurred from 1870-1880, Table 1.--Results of climate-based regression models

				Verification period (r)					
Site	Aspect	Forest	1st 3 months entering @ .10	1856-1884	1941-1960	1961-1981	Disturbance	r^2	1961-1981
Hunter Mt., NY	O	T	Dec.Aug	-.17	.61***	-.11	1887	.12	.00
Plateau Mt., NY	O	T	Dec., -pAut	.41***	.77***	-.13	u	.17	.02
Whiteface Mt., NY	E	B	Dec., -pAug	.31	.59***	-.12	?	.17	-.01
Whiteface Mt., NY	E	T	-pAug	.13	.73***	.26	1895_1	.15	.00
Whiteface Mt., NY	W	B	-pAug, Oct, Dec	.42**	.43**	.07	u	.43	.01
Whiteface Mt., NY	W	T	Dec, Apr, June	.26*	.32*	-.21	1895_1	.23	.02
Mt. Mansfield, Vt	E	B	-Jul, Dec, Oct	.35**	.58***	-.04	u	.36	.00
Mt. Mansfield, Vt	E	T	Jan, -pAug, Dec	.48***	.77***	-.19	u	.38	.02
Mt. Mansfield, Vt	W	T	-pJul, Dec, Mar	.22	.48**	-.44	1935	.26	-.02
Mt. Washington, NH	E	B	-pJul, pSept, pMay	n.d.	.35*	.03	u	.29	-.04
Mt. Washington, NH	E	T	Jan, -pJul, Dec	n.d.	.71***	-.14	1880	.30	-.02
Mt. Washington, NH	W	B	-pJul, pSept, Dec	n.d.	.70***	.01	1880	.49	-.02
Mt. Washington, NH	W	T	Dec, -pAug, -pJul	n.d.	.70***	-.07	1885_1	.44	-.01
Lake Arnold, NY	NE	B	-pJul, Dec, -pAug	.42**	.47**	-.07	u	.55	.01
Whiteface Mt., NY	E	H	Jun, Jul	.40**	.04	.03	1952	.18	-.02
Whiteface Mt., NY	W	H	-pAug, -Jul, Dec	.10	.46**	.33*	1895_1	.17	.02
Mt. Mansfield, Vt	E	H	Dec, -pAug,-June	.47***	.50**	-.05	1920_1	.31	-.02
Mt. Washington, NH	E	H	-PAug	n.d.	.38**	.01	1901_1	.09	
Mt. Washington, NH	W	H	-pJul, Dec, -pAug	n.d.	.66***	-.14	1885_1	.41	-.02
Keene Valley, NY	SW	M	-Oct,-pJul, Aug	-.04	.48**	.44**	1850	.23	-.05
Spruce Glen, NY	O	M	pMay, Nov, -May	.416	.55***	.29*	1870	.41	

B = boreal forest, T = transition forest, H = predominantly hardwoods
The boreal and hardwood zones at Mt. Mansfield had too few reliably dated cores for analysis.

U = no evidence of major, standwide disturbance after 1850.

1 = logging or other major disturbance in year noted.

r = correlation coefficient for climate-predicted vs, actual standardized ring width.

r^2 is for the calibration period, 1885-1940..

*,**,*** = .10, .05 and .01 significance level for r

pJul (etc.) is the July prior to the summer of ring formation.

x is the mean of the observed - predicted standardized ring width for 1961-1981. These small values indicate that the spline fits the raw ring widths well during the period of declining ring width.

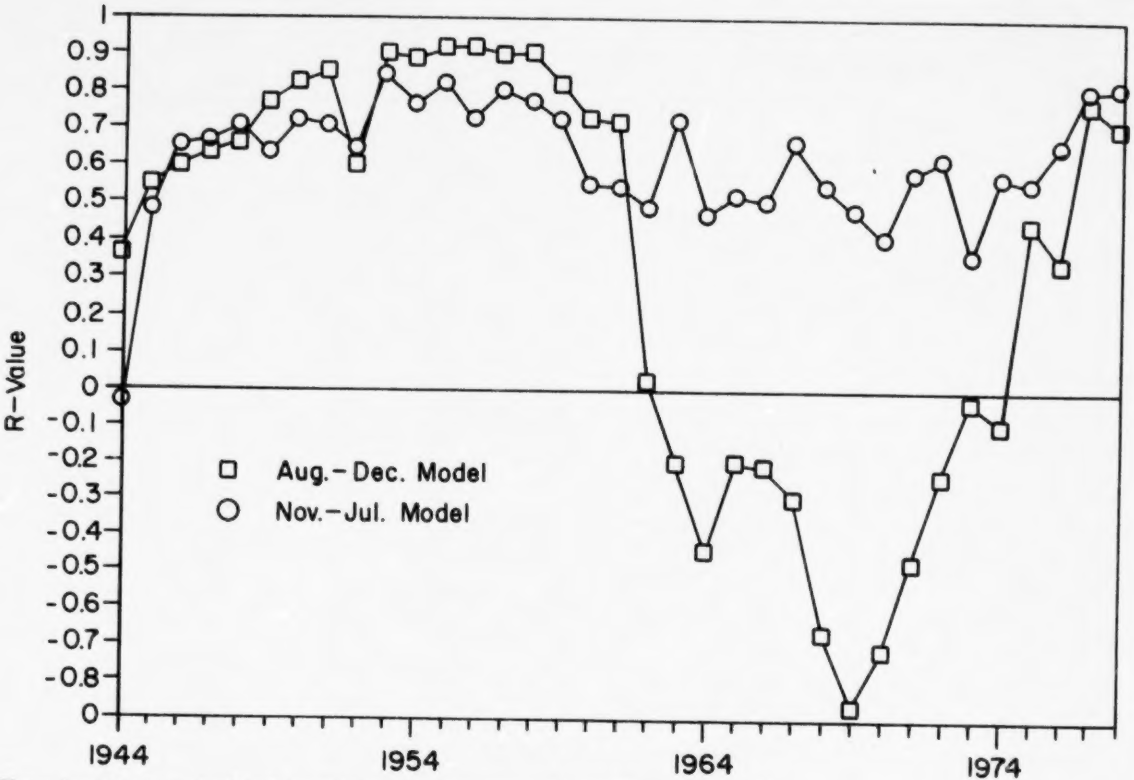

Figure 3.--Actual standardized ring widths and those predicted by the August-December temperature model. Values are regional standardized ring widths values (eight high elevation sites) and those estimated from average monthly temperatures calculated from the average of Durham, NH and Burlington VT values. Correlation coefficients are for predicted vs. observed values for 1941-1960 and 1961-1981.

1935-1950 and 1956-1980. The decade of the 1870's is particularly notable as it contains the only two years which have both unusually warm Augusts and unusually cold Decembers. Field reports indicate that the three major periods of red spruce mortality began in or about 1871 (Hopkins 1901), 1938 (Bermingham/McIntyre 1938) and probably around 1962. Those periods of mortality involved spruce beetles and some speculated that climate was involved (e.g. Hopkins 1891, Seventh Report of the Forest Commission (NY), 1891). The episode of the late 1800's as noted previously, was responsible for very heavy spruce mortality in the Adirondacks (an estimated 50% of the mature spruce died) and reports from New Hampshire and Vermont suggest very heavy mortality there as well (Hopkins 1901). The spruce mortality of the 1930's was only reported in New York. Further discussion of the historical aspects of spruce mortality are reviewed by Johnson et al. (1986) and Weiss et al. (1985).

In summary, periods of severe and regionwide red spruce mortality are temporally consistent with periods of particularly warm Augusts and/or cold Decembers. The most recent unfavorable climatic period was characterized by warm Augusts in the 1950's with cold Decembers in the late 1950's and early 1960's.

There are recorded observations which suggest that severe winter damage (dessication, freezing or both) was the key factor which triggered the recent spruce decline. Reports of severe winter damage to foliage (sometimes confined only to the newest foliage), sometimes accompanied by extensive bud mortality and tree death, have been widespread across New England since about 1959 (Friedland et al. 1984, Weiss et al. 1985, Johnson et al. 1986, and figure 7). Reports noting severe browning episodes were particularly frequent and widespread in the early 1960's. Patches of high elevation spruce in New Hampshire were judged to have been killed by severe winter conditions by 1962 or 1963. (Kelso 1965, Wheeler 1965, Tegethoff 1964, D. Stark, unpublished field notes). In 1963, studies or repeated visits to affected sites were initiated in some places to follow the progress of the injured trees (e.g. Tegethoff 1964, Stark 1962). Based on the concurrence of the synchronous downturn in ring width across the study sites,

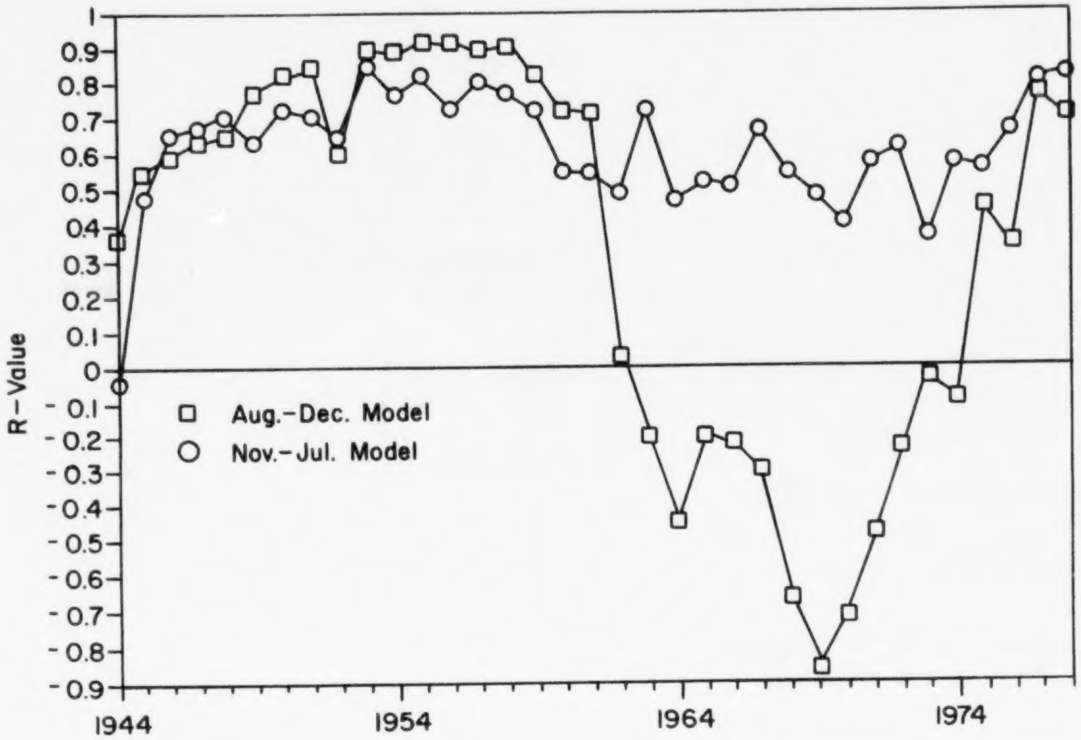

Figure 4.--Seven-year running correlation coefficients for actual vs. climate-predicted standardized ring widths. Squares reflect the predictive ability of the August-December temperature model and (+) reflects the predictive ability of the November-July temperature model. Data are regional averages as in Figure 3.

the many reports of spruce mortality in 1962-65, and the change in the tree-ring-climate relationship in the early 1960's it is reasonable to suspect that the frequent winter damage served as a synchronizing and initiating factor which started a sequence of decline. This assertion conforms with the fact that the recent (post-1960) foresters' reports from which figure 5 is drawn often attribute spruce mortality to severe winters.

The effect of several closely-spaced damaging winters might explain the shift in tree-ring width as shown in figure 1. Perhaps severe winter damage to foliage and buds shifted carbon allocation in favor of producing new shoots and foliage and away from wood production.

Use of the winter damage reports (some of which are anecdotal) should, of course, be viewed cautiously, but the correspondence of reports issued by many different observers over the New York-New England region suggests regionwide effects. Records of forest problems in the Adirondacks are continuous back to about 1911 (New York State, 1911-1977), and the Maine reports were compiled by a single observer after 1957 (Stark, 1957-1977). Thus, the New York and Maine records are probably the most reliable.

Spatial Consistency

If climatic stress is an important determinant of spruce decline, then the regional pattern of mortality, symptoms and tree-ring characteristics should be spatially consistent with climatic anomalies. In the eastern U.S., the 1960's were characterized by unusually cold winters (Namias 1970) and climate records for the Northeast show that there was a strong gradient in the departure from normal temperatures with the most unusual temperatures in western New England and New York and near-normal temperatures in central and eastern Maine (Namias, 1970). Unfortunately we do not have sufficient data at present for a statistically rigorous analysis of the spatial consistency between winter temperature conditions and high-elevation spruce decline.

Drought

During the 1960's widespread drought in the Northeast was prolonged and particularly severe (e.g. Cook and Jacoby, 1977), and the potential for drought as an initiating stress in other declines has been noted (i.e. Manion 1981, Houston 1981, Burgess

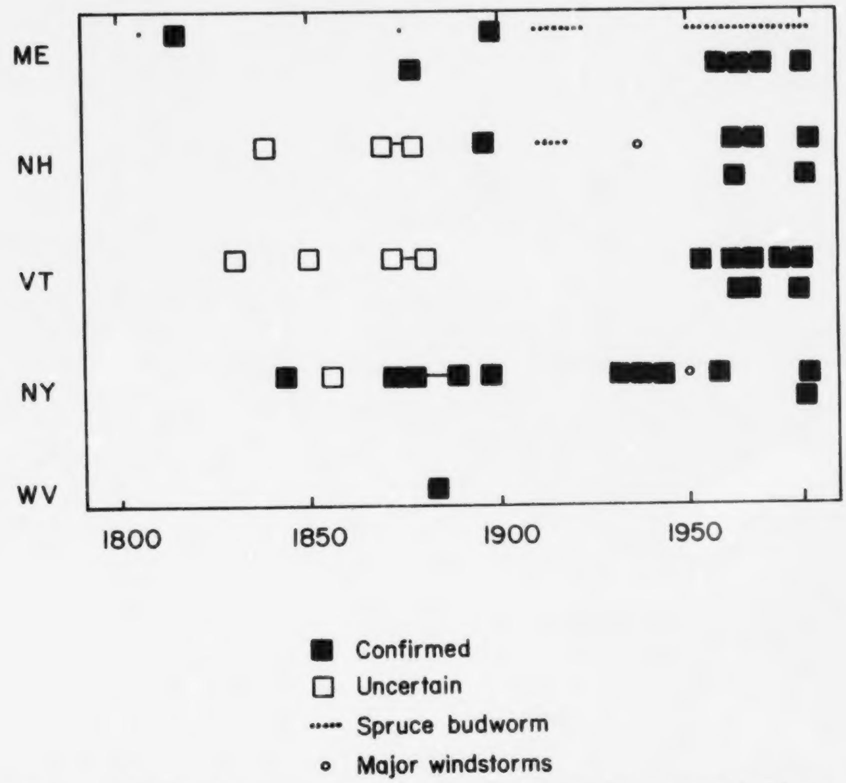

Figure 5.--Periods when extensive or severe red spruce mortality were noted. After Johnson et al. 1986.

et al. 1984). Information relating to the importance of the mid-1960's drought in the high elevation forests is conflicting. Spatial patterns do not strongly suggest drought as a major factor, since precipitation during the drought increased with elevation (Siccama 1974, Johnson and McLaughlin 1986) where mortality has been the greatest. On the other hand, the high elevation soils are thinner and hold less water. Temporally, the available evidence shows clearly that there were major episodes of high-elevation spruce mortality in progress by 1962 or '63, two years prior to severe drought (e.g. Tegethoff, 1964) which had the same symptoms and characteristics which have been reported more recently.

On the other hand, although drought index is not correlated with the standardized ring widths or with residuals from the temperature regression models, the tree ring analyses often show strong negative residuals from the temperature-based predictions during 1965-67 (figure 3) suggesting that drought may be a stress adding to the decline syndrome. It is also noteworthy that the 1870's were a decade of stressful temperature (figure 6) and severe drought (Cook and Jacoby, 1977). The climatological similarities of the two most severe periods of spruce mortality are intriguing and worthy of further study.

Summary

Climatic influences are thought to play important roles in the decline of other tree species, and the available evidence indicates that cold early winter temperatures are a triggering factor in the current spruce decline. Major periods of red spruce mortality, including the recent one, are temporally and spatially consistent with unfavorable winter temperatures. A climate-driven mechanism which could initiate a decline--severe winter damage to foliage and buds--is documented in field reports. Drought may be another climatic factor helping to synchronize or initiate the mortality, and its effect may be less regional and more site specific. The evidence implicating drought is weaker than that implicating winter damage.

We do not believe that findings of climate involvement rule out other possibilities such as air pollution stress. Based on the findings presented here, we suggest that research on the effect of air pollution on the ability to withstand freezing and desiccation in winter is of considerable importance.

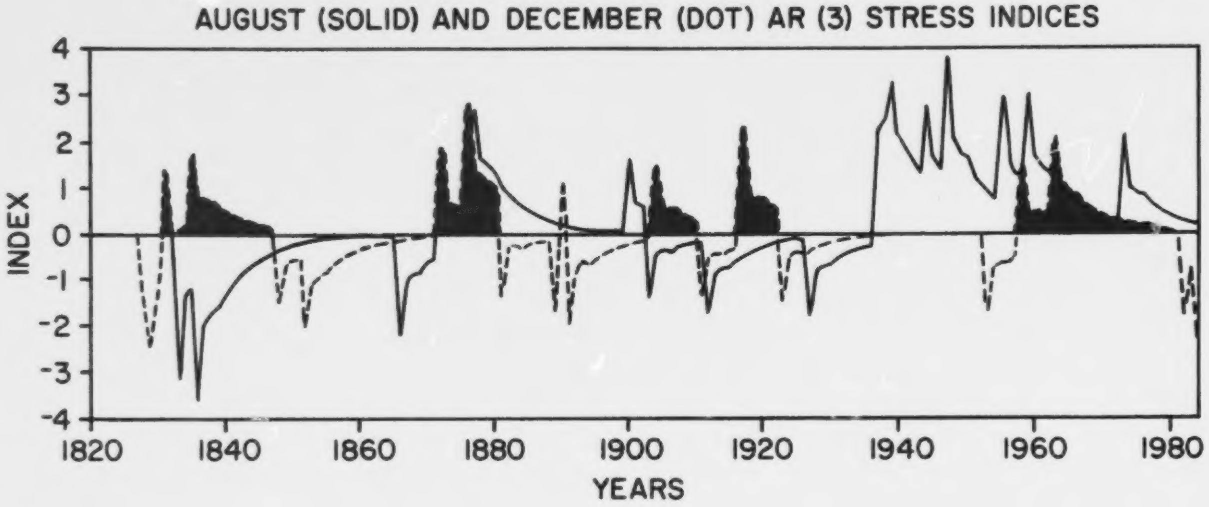

Figure 6.--Years when warm Augusts and/or cold Decembers occurred. Only monthly average temperatures which have a probability < .05 are included. The carry-over of favorable (negative index values) and unfavorable (positive index values) years is approximated by the AR 3 model which represents the persistence inherent in the tree ring series at the high elevation sites of table 1 (Johnson et al. 1987).

Acknowledgements

We thank Jonathan Dushoff who assembled the historical data on winter damage, and contributed to the regression analyses. This work was supported by a grant from the Andrew W. Mellon Foundation.

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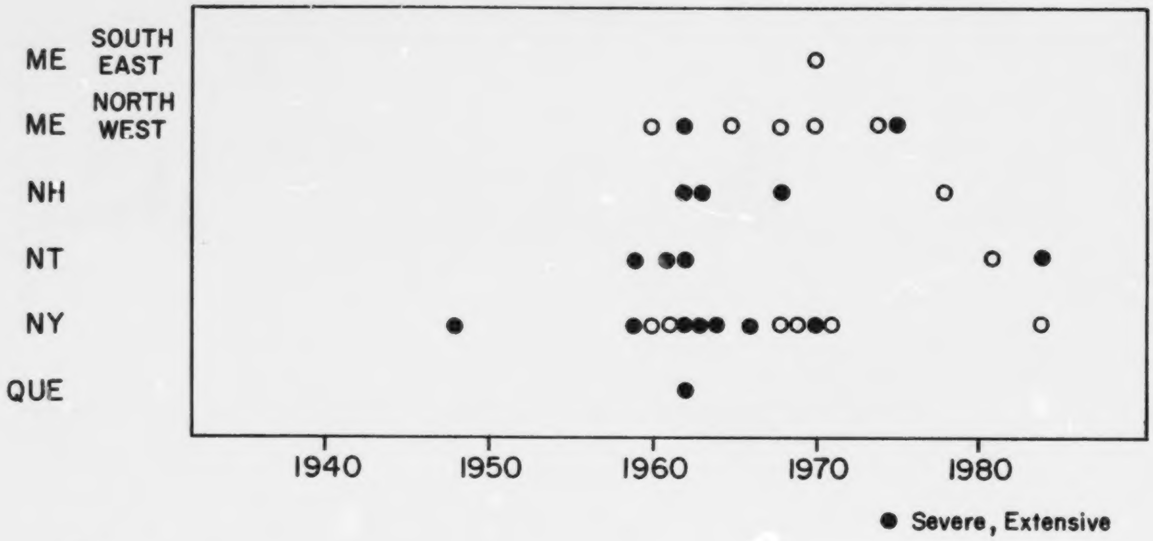

Figure 7.--Reports of "winter drying", "winter burn", "winterkill" etc. where red foliage was observed in early spring. The tabulated incidents were generally widespread within the geographic area. After Johnson et al.,1986.

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Threshold Responses and Climatic Change: Possible Contributors to the Decline of Red Spruce

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Abstract

Climate as a potential contributor to the decline of red spruce is examined. Previous climatic response model work is reviewed and a new approach based on a threshold response is considered. An exploratory analysis of positive and negative threshold responses to temperature and precipitation revealed a positive threshold response to November and April temperatures, along with some previously discovered temperature variables. These threshold responses appear to be due to climatic warming through the 20th century. Since 1960, these temperatures have generally declined. The possible contribution of these decreasing temperatures to the red spruce decline is discussed.

Introduction

The possible role of climate in promoting forest decline has received recent attention due to the unexplained decline and mortality of red spruce (*Picea rubens* Sarg.) in the Appalachian Mountains of eastern North America. Although air pollution has been suspected as causing this decline (Johnson and Siccama 1983; McLaughlin 1985), the currently available evidence for pollution effects is largely circumstantial and generally unconvincing (Woodman and Cowling 1987).

A particular symptom of decline in red spruce is the synchronous reduction of radial increment since about 1960 in most sampled stands (Johnson and McLaughlin 1986; McLaughlin et al. 1987). Although this ringwidth reduction is commonly found in spruce growing at all elevations, its presence in spruce growing in the mixed-hardwood zone below about 800 meters elevation is believed to be caused by competition and canopy-closure effects in response to past logging activity (Hornbeck and Smith 1985; Federer and Hornbeck 1987; Van Deusen 1987). Yet, above 800 meters elevation, this ringwidth reduction also occurs in uneven-aged stands of old-growth red spruce with no known cutting history and in stands with markedly variable disturbance histories.

Figure 1 shows overlay plots of 25 mean ringwidth series, scaled to a common mean of 1.0, which were developed from stands of red spruce above 800 meters elevation in New York, Vermont, and New Hampshire. Each series is actually a mean-value function of the ringwidths from 10-20 trees sampled at a given site. Also shown is the grand mean of the 25 mean ringwidth chronologies. The overlay plots reveal a general convergence in pattern after about 1910 and a very consistent reduction in ringwidth beginning about 1960. This latter effect is even more clearly revealed in the grand mean. This synchronous reduction in ringwidth cannot be easily explained by stand dynamics arguments alone (McLaughlin *et al.* 1987). Coupled with forest survey data (Siccama *et al.* 1982; Johnson and Siccama 1983; Scott *et al.* 1984) that indicate a high incidence of spruce mortality since 1960, it is now generally accepted that the post-1960 ringwidth reduction in red spruce growing above 800 meters elevation is a symptom of an anomalous forest decline that is as yet unexplained.

Previous Climatic Response Model Results

In an attempt to determine if climate could be responsible for this decline, Cook (1987), Cook *et al.* (1987), McLaughlin *et al.* (1987), and Johnson *et al.* (1988) modelled the climatic signal of red spruce tree-ring chronologies from mountain sites in New York, Vermont, and New Hampshire. In each study, mean monthly temperatures were linearly regressed against suitably transformed ringwidth chronologies. The time period for developing the regression model was 1885-1940 in Cook et al. (1987) and Johnson et al. (1988). The other studies used slightly different time periods for regression analysis. The resultant empirical climatic response models were validated against withheld tree-ring data prior to 1960 (typically 1941-1960 tree rings) and then used to forecast ringwidth variation through the post-1960 decline period. In each study, the results were the same: the climatic response models could usually predict tree ring variations in the 1941-1960 period, but not in the post-1960 period for any stands above 800 meters elevation. These results were further evidence for the anomalous nature of the red spruce decline and suggested that an additional stress, such as pollution, might have changed the way in which the trees responded to climate.

The aforementioned climatic response studies revealed another remarkably consistent finding. Red spruce growing above 800 meters elevation grew wider (narrower) rings when July and August temperatures of the previous growing season were below (above) average and when December and January temperatures prior to the current growing season were above (below) average also. Although the physiological basis for these relationships is not well understood, the consistency of these results using different climate and tree-ring data sets indicates that such a basis must exist.

Cook *et al.* (1987) and Johnson *et al.* (1988) examined the temporal history of August and December temperatures extending back over 150 years. They found a coincidence between years of temperature stress (unusually warm August and/or cold December temperatures) and past red spruce declines. In addition, they found that the current decline was preceeded by an abnormally high frequency of temperature stress-years in the 1940's and 1950's. These stress-years were followed by occurrences of winter freeze or dessication damage to spruce foliage in the 1960's (Johnson *et al.* 1988). However, most

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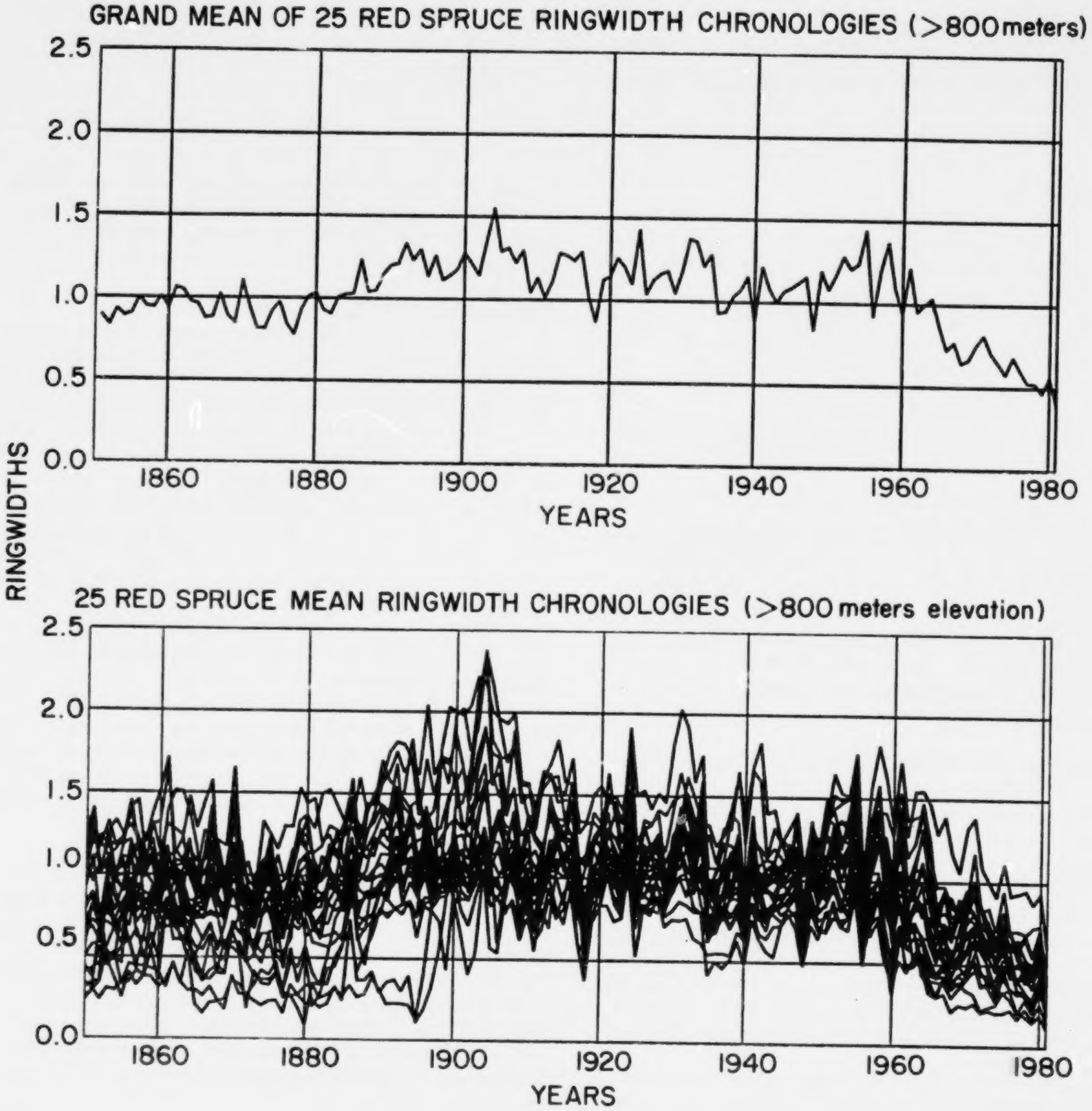


Figure 1.--Plots of 25 mean ringwidth series, all scaled to a mean of 1.0 the upper figure is the grand mean and the lower figure is the overlay of the 25 series. Note the snychonous reduction in ringwidth after 1960 in all series.

of these "winter drying" events were not associated with stressful temperatures, as defined above. With these findings, Johnson *et al.* (1988) proposed that abnormally high temperature stress could have predisposed or incited the red spruce trees to decline, either alone or in consort with pollutants, by making them more susceptible to winter foliar damage.

Although the climate predictions of tree rings in the post-1960 period uniformly failed to match the actual ringwidth patterns, Johnson *et al.* (1988) observed that the post-1960 patterns agreed well between sites across New York, Vermont, and New Hampshire. They postulated that, regardless of the cause of the breakdown in the climate predictions, the actual data had to be reflecting broad-scale environmental influences on tree growth in the post-1960 period. A new comparison of the monthly temperature data with the average data spanning 1941-1981 (the time period used for model validation and tests of prediction in the post-1960 period) revealed that November temperatures prior to and July temperatures during the current growing season could largely explain the ringwidth patterns in this period. This occurred in spite of the lack of predictive skill in either variable in the regression modelling phase. Most significantly, this success carried through the 1962-1974 period which was impossible to predict from the previous climatic response models.

Like the December and January temperature relationships, above-average November temperatures contributed to better growth and a wider ringwidth the following growing season. However, the current July response was inverse to the previous July-August responses described earlier.

Thus, it appears that there was not a total loss of climatic response in declining red spruce, as had been suggested by the earlier studies. Rather, there was an apparent change in climatic response from about 1962 to 1974 (Johnson *et al.* 1988). The cause of this apparent change was not clear. Given the relatively short span of years in which the November-July model clearly out-performed the previous temperature response models, it is possible that this new relationship is spurious. However, the 1960's decade was also the time of extreme drought in the northeastern United States. Therefore, it is also possible that climatic conditions during the 1960s exceeded some critical threshold that altered the way in which red spruce responded to climate. For this reason, an exploration for threshold climatic variables was conducted.

Selection of Threshold for Exploration

A major difficulty in searching for threshold variables in tree growth-climate studies is the lack of an *a priori* model for selecting the threshold variables and the thresholds beyond which the variables become influential. For this reason, a very simple, exploratory approach was taken.

The tree-ring data from New York, Vermont, and New Hampshire were first regionalized into a single time series. This was accomplished by log transforming and first-differencing the ringwidths from each site, following the method of Van Deusen (1987). First-differencing emphasizes the high-frequency variations in the series at the expense of low-frequency fluctuations. This follows from the notion that the 1st-differences are numerical estimates of the 1st-derivative of the ringwidths (Van Deusen 1987).

The transformed ringwidths were averaged together using a robust mean (Mosteller and Tukey 1977) to discount the influence of cross-sectional outliers in the data. The resultant mean-value functions were then subjected to principal components analysis (Cooley and Lohnes 1971) for the common interval 1856-1976.

This procedure was done for 31 red spruce ringwidth data sets. They cover all elevations and include both old-growth and anthropogenically disturbed second-growth stands. Figure 2 shows the log eigenvalue trace and the loadings of the 1st-eigenvector. The 1st-eigenvalue accounts for 63.3% of the total variance. The subsequent log eigenvalues are all much smaller and decline in a nearly linear fashion. It appears that there is one dominant regional signal in the spruce data. The 1st-eigenvector loadings reveal the spatial consistency of this signal. The loadings across New York (NY), Vermont (VT) and New Hampshire (NH) are remarkably consistent, except for four loadings representing low-elevation (< 800 meters) mixed-hardwood zone spruce sites (H). For all sites above 800 meters elevation and some low-elevation sites, it makes little difference if red spruce is sampled in New York, Vermont, or New Hampshire. The high-frequency information content in these tree-ring series is largely the same.

Figure 3 shows the scores of the 1st-eigenvector. It is an expression of the common signal in the tree rings, as defined by the 1st-eigenvector. An interesting feature of the scores is an increase in variance up to about 1960, the beginning of the current decline. It suggests that environmental variability leading up to the decline increased markedly, with a slightly higher frequency of negative extremes over positive extremes. Perhaps, this increase in variability reflects more frequent crossings of climatic thresholds. However, it may also mean that the trees were becoming increasingly sensitive to environmental influences because of pollution effects.

Threshold Model Results

The striking evolution of extremes in figure 3 suggested that their occurrence could be used to search for threshold climatic variables. To select a threshold, the scores were first normalized to zero-mean and unit-variance. The years for which a search for threshold variables would be made were those in which the scores exceed ± 1 standard deviation from the mean. A total of 25 years exceeded this threshold. In addition, the years were segregated into positive and negative threshold exceedence catagories. This results in 11 positive exceedences and 14 negative exceedences. The reason for the segregation was the belief that different climatic variables may be responsible for the positive and negative excedences. Figure 4 shows the normalized scores and the years selected for threshold analysis. It is clear the the frequence of threshold exceedences is not random.

The exploration for threshold variables was done in an extremly simple way. For each year exceeding the threshold, a 16-month dendroclimatic year was created, beginning in May of the previous growing season and ending in August of the current growing season. The 16 monthly values were then averaged across years of positive or negative threshold exceedence to form mean expressions of positive and negative threshold climatic response.

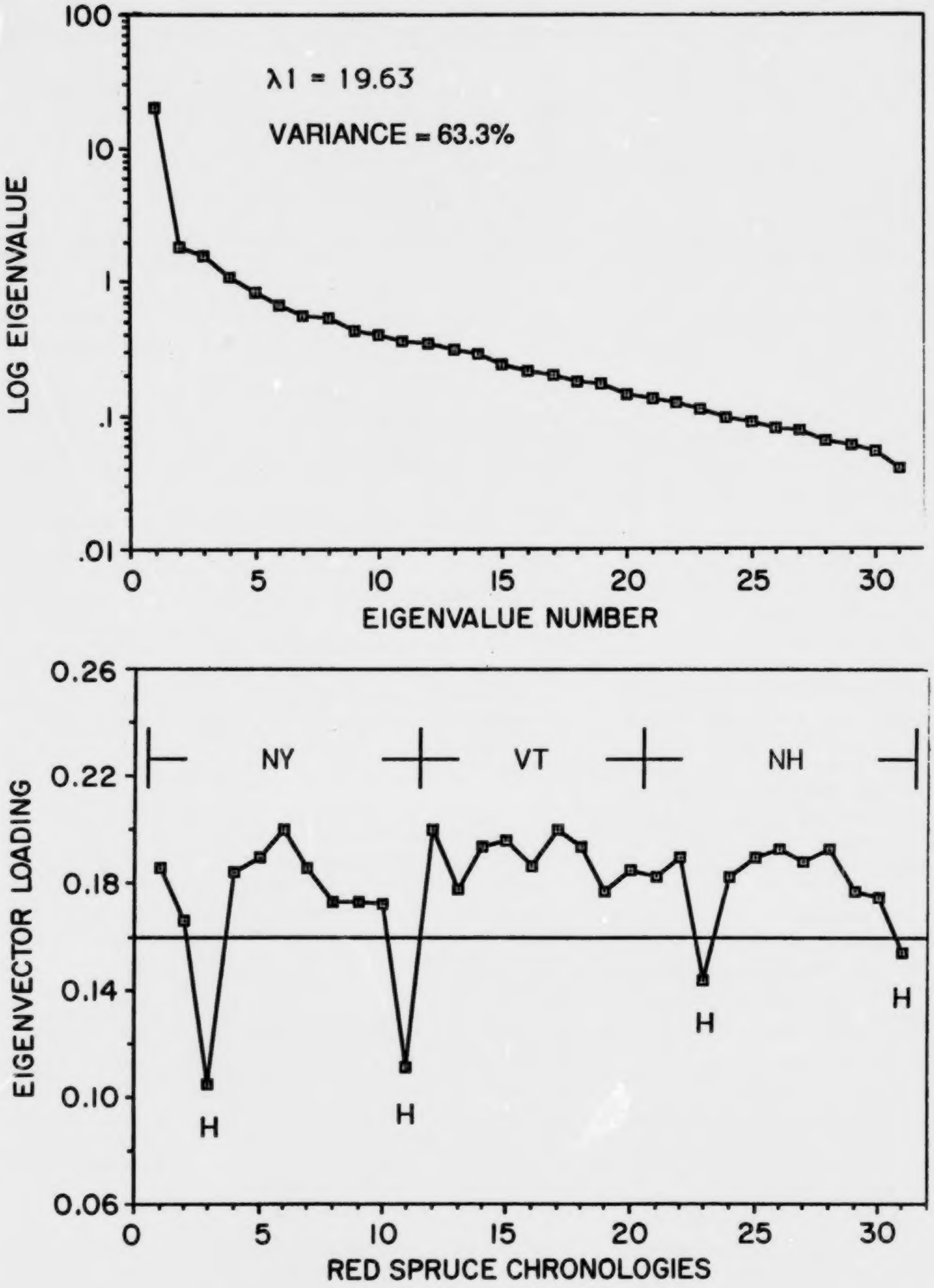


Figure 2.--The log eigenvalue trace and 1st-eigenvector loadings of 31 red spruce chronologies sampled in New York (NY), Vermont (VT), and New Hampshire (NH). Except for 4 anomalous loadings representing lower-elevation, mixed-hardwood sites (H), the chronologies appear to have the same relative information content.

The climatic data used for this purpose were long-term temperature and precipitation records from Canton and Plattsburgh, New York, Burlington, Vermont, and Hanover, New Hampshire. These records were obtained from the United States Historical Climatology Network. All records in this network have been carefully screened for data quality and adjusted, when necessary, to ensure data homogeneity.

Given the regional nature of the eigenvector scores, the temperature and precipitation records were averaged together as normalized regionally monthly climatic departures, extending from 1835 to 1984.

The mean threshold climatic models for temperature and precipitation are shown in figures 5 and 6, respectively. Each monthly mean has 2-standard error limits included. No formal significance testing was carried out because of the exploratory nature of this exercise, the small sample sizes involved, and the appearance of non-normality in several instances. The non-normality is high-lighted by the inclusion of the monthly medians in each plot. Large differences between the sample mean and median is a good indicator of asymmetry in the sample distributions. The 2-standard error limits are used here only to indicate which monthly variables might be considered as threshold variables in later formal significance testing. For that purpose, bootstrap confidence intervals (Efron 1987) will be developed.

In figure 5, the plot of the mean positive temperature response indicates that prior July and August, November and December, and April temperatures contribute to years of positive threshold exceedence in red spruce. The prior July and August variables are consistent with the previous climatic resonse model results, as is the December variable. The November variable is also consistent with the relationship discovered by Johnson *et al.* (in press). However, the April variable is new.

In figure 5, the plot of the mean negative temperature response indicates that only prior June, December and January temperatures contribute to years of negative threshold exceedence. The December and January variables are consistent with previous results, but the prior June variable is new. Neither the prior July nor prior August means exceed the 2-standard error limits, although their signs are consistent with previous models.

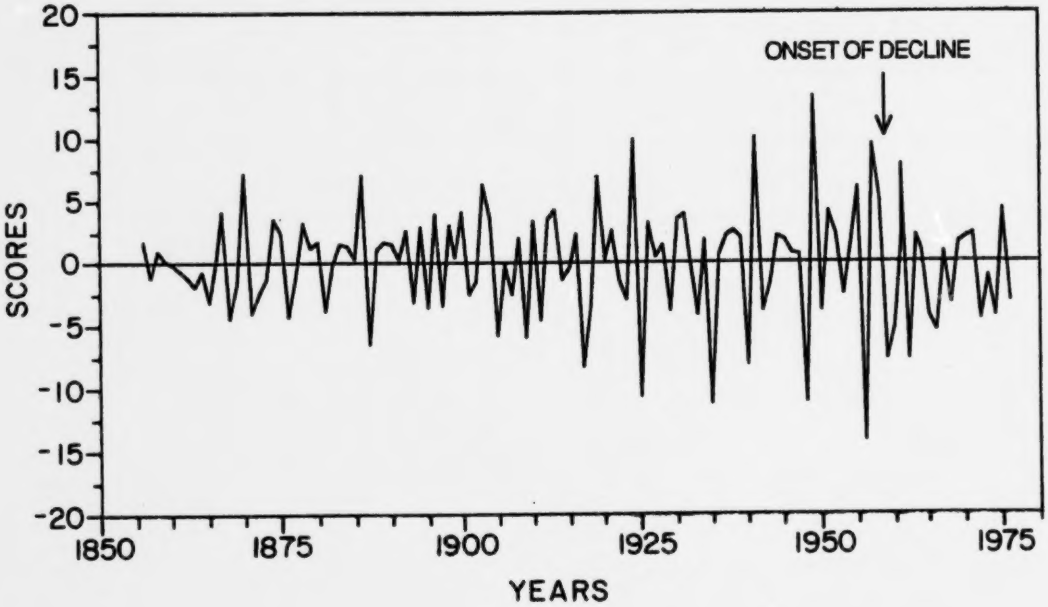


Figure 3.--The 1st-eigenvector scores derived from the loadings in figure 2. Note the increase in variance in the series up to about 1960, just prior to the start of the red spruce decline.

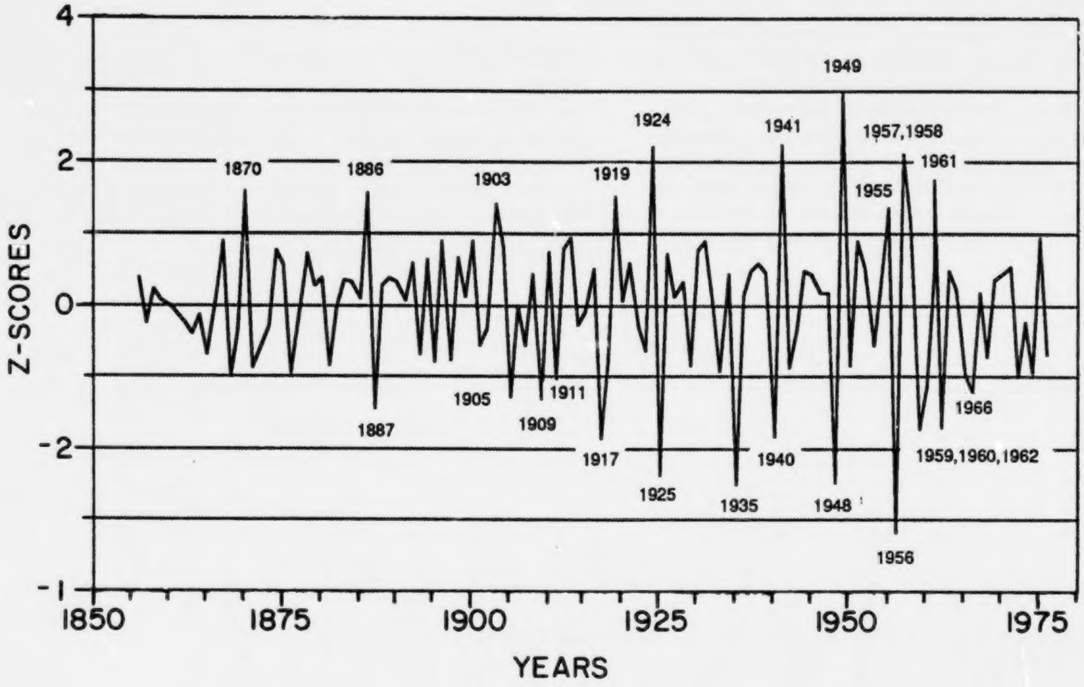
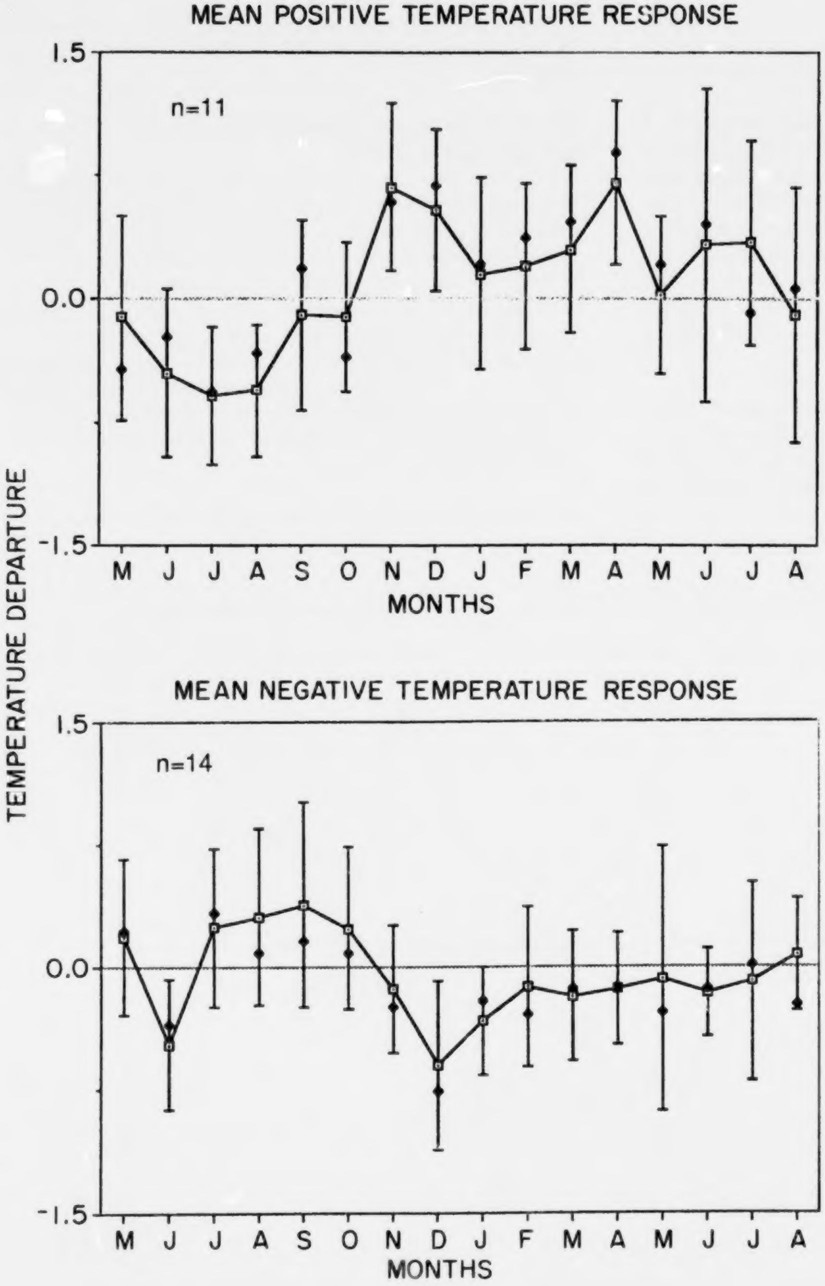


Figure 4.--The normalized 1st-eigenvector scores. Those years exceeding ± 1 standard deviation are labled. These years are used in the threshold response analysis.


MEAN POSITIVE TEMPERATURE RESPONSE

MEAN NEGATIVE TEMPERATURE RESPONSE

Figure 5.--The positive and negative temperature threshold response models for red spruce. Each mean value has an associated 2-standard error bar plotted with it. The sample medians (solid dots) are also shown to high-light some problems of non-normality in some of the samples. For this reason, the means and their error bars should be interpreted with caution.

The positive and negative threshold models shows some clear consistency with the previous climatic response models used for prediction. They suggest that prior July, August, and December temperatures are linearly related to red spruce growth across the range of response in ringwidth. However, the November and April temperatures seem to be related only to positive exceedences. An overlay plot (figure 6) of the positive and negative temperature responses suggests another intriguing difference between these threshold models. There is asymmetry in the threshold models, largely in the prior June through December months, due to a one-month lag in the negative threshold model relative to the positive threshold model. Without a better understanding of the statistical significance of these patterns, it is difficult to place much meaning in this apparent lag.

The threshold models for precipitation are shown in figure 7. Only two months show any potential significance at all: prior August in the positive threshold model and December in the negative threshold model. Given the lack of past success in modelling red spruce with precipitation data, it is difficult to assess the meaning of these results. There may simply be a correlation between temperature and precipitation for those months that is creating this effect.

Threshold Responses, Climatic Warming, and Red Spruce Decline

The positive threshold response to warm November and April temperatures could be a significant clue in understanding the climatic side of the red spruce decline. If, after about 1960, the positive influence of these variables were suddenly "turned off" by an abrupt change in climate, then red spruce may have been more susceptible to other stresses such as pollution. Figure 8 shows plots of November and April temperatures covering 1856-1984. It is quite apparent that each series has a significant positive trend. These trends are consistent with the general belief that the earth, in general, is warming. Whether or not this warming is caused by "greenhouse" gases is irrelevant to the matter at hand.

November temperatures show the greatest trend and have a very

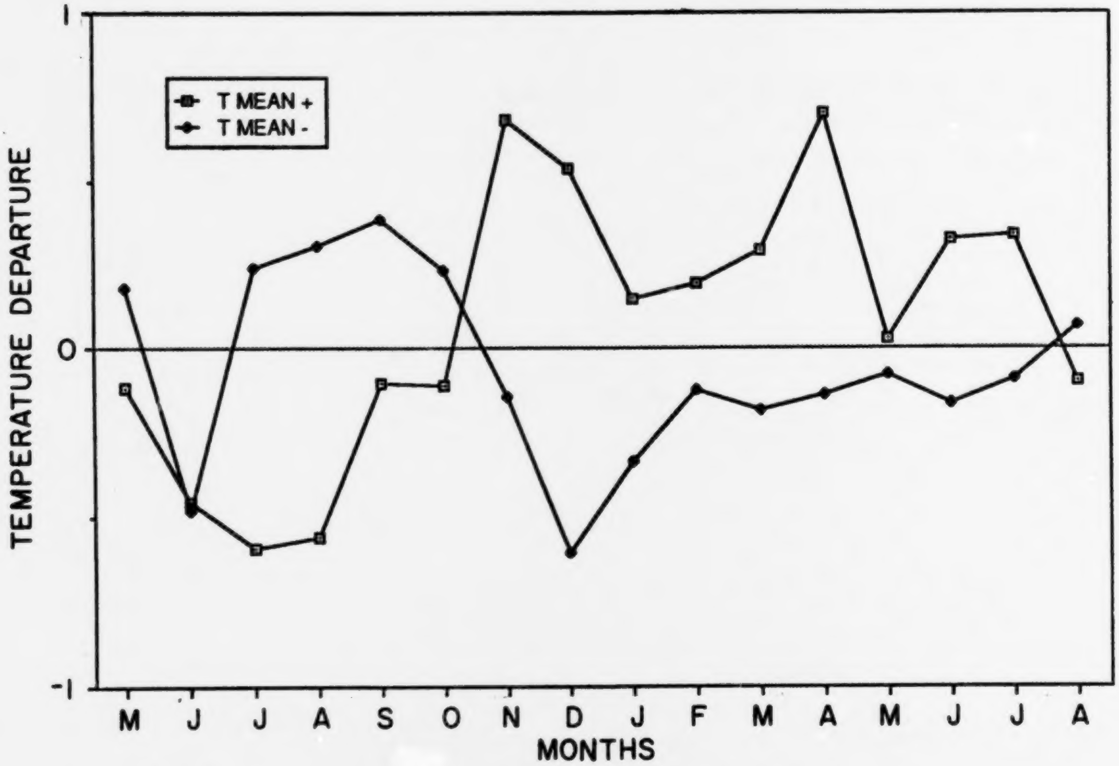


Figure 6.--Overlay plots of the mean positive (T MEAN +) and negative (T MEAN -) threshold response models. Note the 1-month lag in the negative responses compared to the positive responses from June to December.

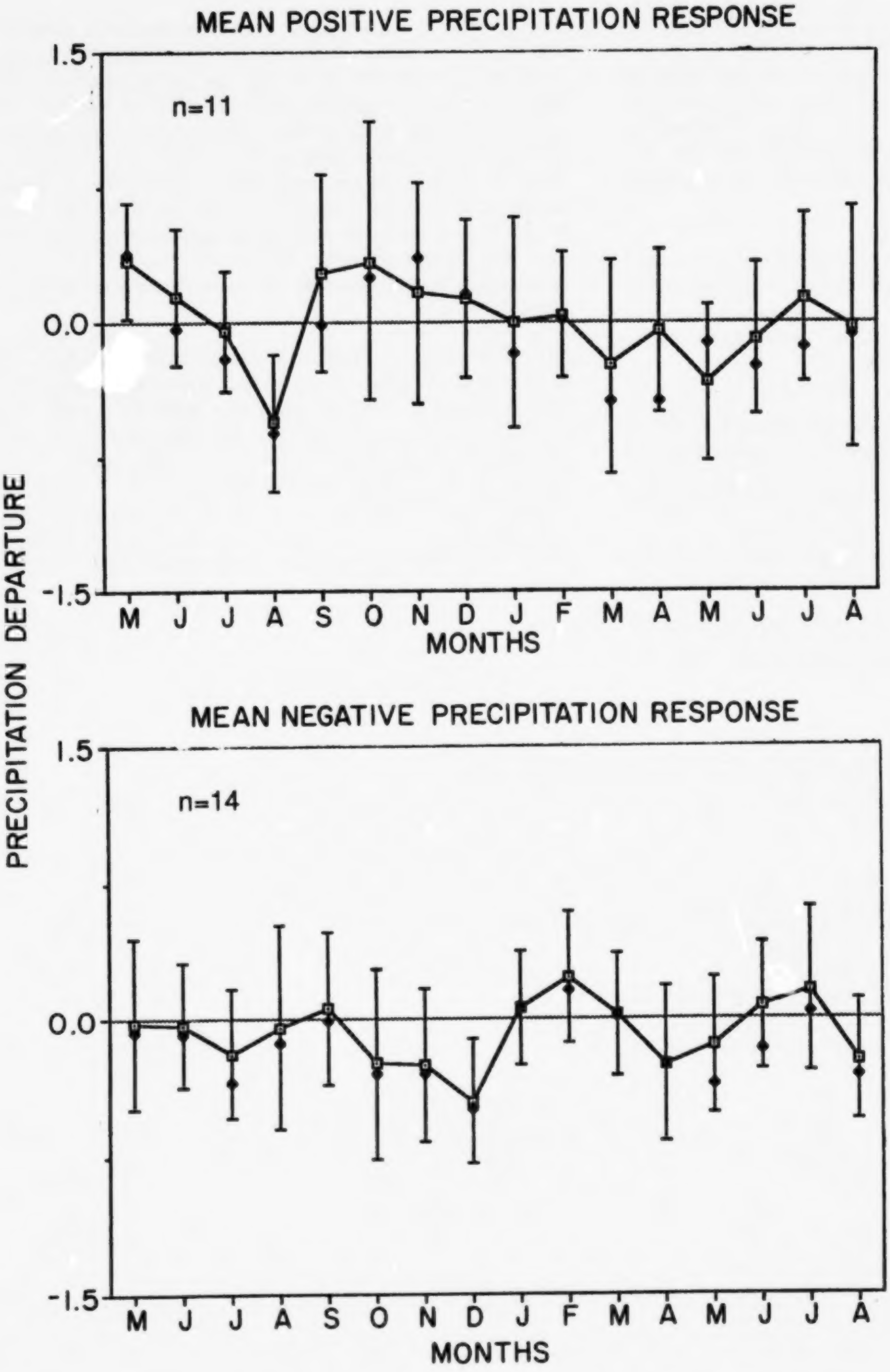


Figure 7.--The positive and negative precipitation threshold response models for red spruce. See the figure 5 caption for more details.

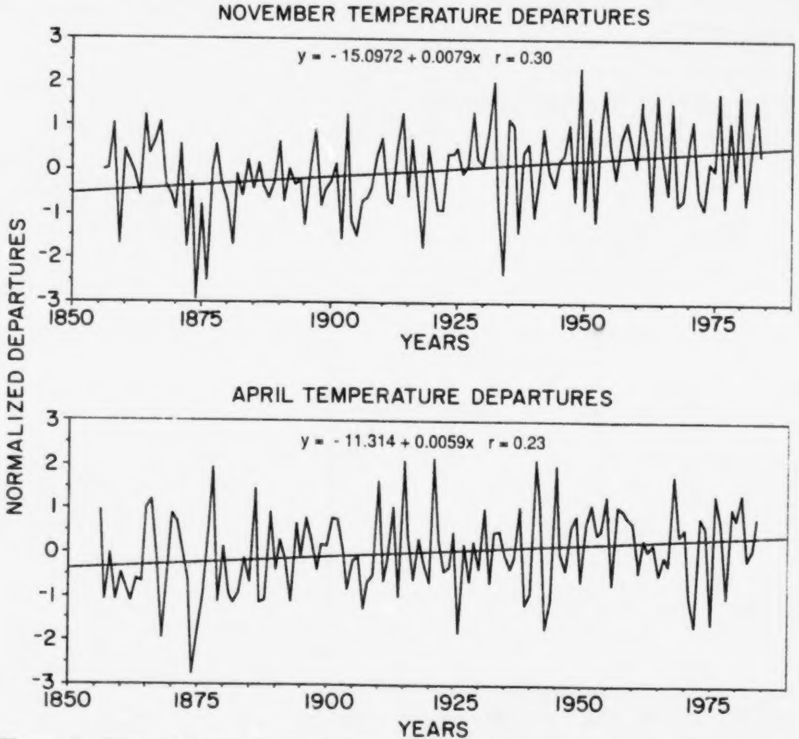
high frequency of departures exceeding + 1 standard deviation since 1945. It is this high frequency of warm Novembers that probably caused the correlation between November temperatures and red spruce tree rings in the 1941-1981 period (Johnson *et al.* in press). Thus, red spruce appears to be capable of responding in a transient sense, to climatic warming. It is likely that the April threshold variable also reflects a transient response to warming climate.

The physiological basis for this transient response may be related to an increase in net photosynthesis both late in the year prior to growth and early in the spring of the current growth year. This would enhance the carbon balance of the trees and provide more carbohydrates for wood formation.

It should also be noted that December temperatures also have a positive trend. Thus, all three temperature variables found in the positive threshold response have been trending in a direction beneficial to red spruce growth for much of the 20th century.

With regards to an abrupt climatic change contributing to the spruce decline, there is an indication of unfavorable temperatures since 1960. Figure 9 shows the mean of November, December, and April temperatures. Note that the overall trend is positive, as before. From about 1940 to 1960, the general tendency is for mean temperatures to persist above the trend line. Based on the positive threshold model results, this period should have been good for radial growth. Such a effect is indicated in the grand mean in figure 1, where mean radial growth was generally increasing from about 1940 to 1960. However, since 1960, there has been a preponderance of mean temperatures below the trend line. The timing of these persistently negative departures corresponds with the sharp decline in mean radial increment in figure 1.

If, as proposed above, these temperature variables are important in maintaining a good carbon balance in red spruce, then the 1960-1975 period cannot be regarded as good for growth. It is possible that this period of generally depressed November-December-April temperatures contributed to the high incidence of winter foliar damage, noted by Johnson et al. (1988) in the 1960s, through a disruption of the trees' carbon balance. Although climate is not yet a proven contributor to the red spruce decline, the results presented here lend further support to this hypothesis.



Figures 8.--Plots of November and April normalized temperature departures. Note the strong linear trend in each series. From about 1940 to 1984, November temperatures were frequently warmer than any time prior to 1940. These trends are thought to be responsible for the positive November and April threshold responses seen in figure 5.

Acknowledgments

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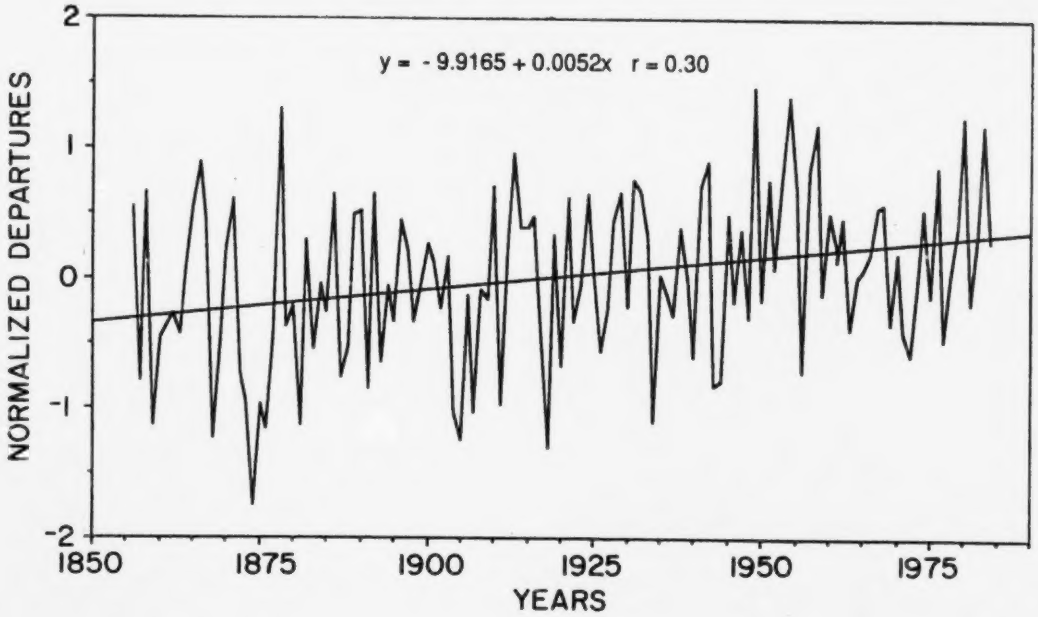

Figure 9.--Mean November-December-April temperature departures. The persistent decrease in these temperatures after 1960 may have contributed to the red spruce decline.

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Population Genetic Variation In New England Red Spruce

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Abstract

Decline in growth rate and increased mortality in high elevation red spruce have been reported for several sites in the northeastern United States. When any major forest tree species enters a period of decline resulting in decreased numbers of individuals in some locales, examination of genetic resources available to that species becomes appropriate and important. The literature on red spruce geographic variation indicates that variation in height and mortality is somewhat limited and that hybrids with black spruce exhibit less winter-drying damage than pure red spruce. A study of red spruce isozyme variation was conducted to examine relationships among genetic variables and decline conditions for red spruce. Foliage samples from over 480 individual red spruce trees were collected from 17 National Vegetation Survey plots in NH, VT, and NY, USA. In addition, more than 200 samples were collected from individual trees in provenance tests of red, black, white, and Norway spruce, for genetic comparison. Known red x black hybrids were obtained from the Petawawa National Forestry Institute, Ontario, Canada, for additional genetic comparisons. All samples were evaluated for over 30 loci detected using horizontal starch-gel electrophoresis. Final comparisons were made using 14 polymorphic loci for all species. Heterozygosity of red spruce is 8%, compared with 20% for black spruce, 23% for white spruce and 16% for Norway spruce. Red x black spruce hybrids averaged 14%. Red spruce also has the lowest number of alleles per locus. Five of 14 polymorphic loci exhibited significant (5%) variation among the 17-plot red spruce sample. Tests of deviation from Hardy-Weinberg equilibrium and calculation of fixation indices reveal that sample trees came from random-mating populations at each plot and that inbreeding is low. Genetic distances among plots are small. Recent European literature presents evidence from comparative experiments that Scots pine and Norway spruce with the lowest genetic variability are affected most by air pollution in both chamber studies and in natural populations exposed to multiple pollutants. Red spruce has a much lower level of genetic variation than any of these species and has, by far, the lowest heterozygosity level of the northeastern U.S. spruces.

Introduction

Harvest and settlement in the northeastern United States in the late 1880's resulted in diminished population sizes of red spruce (*Picea rubens* Sarg.) with remnant populations located at inaccessible higher elevations. In populations of reduced breeding size, decrease in "adaptiveness" through gene loss or fixation may influence the ability of regenerated populations to sustain growth, especially in altered environments which may result from the interactions of pollution effects with climatic change and stand age. Under these conditions, availability and distribution of genetic resources is critical. Quality of gene resources is influenced by the number of different genes and the combinations in which they exist. Availability of gene resources in red spruce populations is influenced by mating structure in stands and gene flow from neighboring populations and possible influx of genes through hybridization with nearby black spruce (*P. mariana* (Mill.) B.S.P.). Lower winter-drying damage has been reported to be correlated with hybrid index scores (Morgenstern 1969 a, b) suggesting levels of hybridization may be important relative to spruce decline in natural stands because hybrids may have potentially greater tolerance for winter drying factors than pure red spruce.

We are examining the quality of red spruce gene resources and the levels of natural hybridization between red and black spruce in National Vegetation Survey (NVS) permanent plots located in New Hampshire, Vermont and New York State. We are also attempting to determine if there is a relationship between genotypic variability of red spruce seedlings and response to ozone fumigation by examination of physiological responses in cooperative studies with the Boyce Thompson Institute, Ithaca, New York.

This research project relates to Spruce-Fir Research Cooperative policy question #1 (Forest Damage) through scientific question 1.2 (What spatial patterns, if any, exist in growth and mortality and in the presence of unusual symptomology in red spruce-fir forests and how do these patterns relate to spatial patterns of pollutant exposure?). The project is determining if relationships exist between genetic resources of red spruce and patterns and trends observed in forest decline. Specifically, our project objectives are:

1. Determine the level of relationship between seedling genotype and physiological responses to O_3 stress in red spruce seedlings.
2. Determine the strength of relationships among decline symptomology, hybridization and degree of introgression with black spruce, and within-stand genetic structure for several northeastern U.S. sites.

This report focuses on the population genetic variability of red spruce.

Materials and Methods

Field Collections

Field sites were chosen which include 17 NVS plots (Weiss *et al.* 1985, Millers and Miller-Weeks, personal communication) in New

Hampshire, Vermont, and New York State. Thirty red spruce trees were sampled at each plot (Gerhard-Gagnon *et al.* 1987). Additional foliar samples were collected from a red spruce provenance test in Colebrook, N.H. and from black and white spruce *(P. glauca* (Moench.) Voss.) plantings in the US Forest Service Massabesic Research Forest, Alfred ME. The red spruce test, planted in 1960 includes 13 provenances from as far south as the Great Smoky Mountains National Park, Tennessee, extending north to the Acadia Forest Experiment Station, Fredericton, New Brunswick (Baldwin 1965). The black spruce test consists of 50 provenances extending from Connecticut to northern Quebec and from Newfoundland west to western Ontario. The white spruce test is an 83 family progeny test of white spruce plus trees primarily from the northeastern US and southeastern Canadian provinces. Both the the black and white spruce tests are aged 16 years from seed (Pete Garrett, personal communication). Black x red spruce hybrids were supplied by the Petawawa National Forestry Institute, Ontario (Tim Boyle, personal communication). Samples of Norway spruce *(P. abies* (L.) Karst.) were collected from 37 trees on the University of New Hampshire campus and 60 samples were provided by Dr. Charles Maynard, College of Environmental Science and Forestry, Syracuse, New York.

All branch samples were collected from fully-exposed upper portions of crowns. Current-year needles were removed and kept cool until they were placed in liquid N_2 (up to 8 h). Foliage samples were then maintained at -80 C in coded locations within an ultralow freezer until electrophoresis.

Electrophoresis

Starch-gel electrophoresis procedures were developed for red spruce foliage based on O'Malley *et al.* (1980). These methods work well with foliage of other species, including the spruces reported here. Initial screening of over 30 loci resulted in our routine use of the 14 polymorphic loci (Table 1) reported here.

Data Analysis

Analysis of allelic variation data was accomplished using the BIOSYS program (Swofford and Selander 1981). Mean observed heterozygosity, the genetic equivalent of Simpson's (1949) index of ecological diversity, was determined for each red spruce plot, and for each spruce species. This value is the proportion of heterozygous individuals for each locus, averaged for all loci. The average number of alleles per locus was also determined for all samples and species. This statistic focuses on allelic "richness" (Brown and Weir 1983) and closely reflects the level of allelic resources available to a species or population. It can be used as an indicator of past genetic "bottlenecks" or of genetic drift. Genetic distance among red spruce plots was calculated as Cavalli-Sforza and Edwards (1967) arc distance. This statistic provides a measure of distance among populations, and is sensitive to differences in allele frequencies. An advantage of this distance calculation is that it reflects differences due to gene flow and genetic drift (Slatkin 1981) but does not reflect differences brought about by mutation. Values near 0.0 indicate high levels of gene flow, while values greater than 0.6 indicate relatively little gene flow (Wright 1978).

Table 1.--Enzymes scored in electrophoresis of red and black spruce foliage.

Enzyme	Importance[1]	Locus designation
Aspartate aminotransferase	S, P[2]	AAT-1,2
Aconitase	R	ACO-1
Diaphorase	R	DIA-2
Glycerate-2-dehydrogenase	R	G2D-1
Isocitric dehydrogenase	S[2]	IDH-1, 2
Malic dehydrogenase	S, R[3]	MDH
6-Phosphogluconic dehydrogenase	R	6PG-1,2
Phosphoglucose isomerase	R	PGI-1,2
Phosphoglucomutase	R	PGM
Uridine-diphosphoglucose-pyrophosphorylase	N	UGPP

[1] S indicates enzyme reported as affected by polluted air; R indicates enzyme is involved in respiration; P indicates enzyme involved in photosynthesis; N indicates enzyme involved in nucleotide formation.

[2] Pollution effects reported by Rabe and Kreeb 1979.

[3] Activity levels influenced by SO_2 in jack pine *(Pinus banksiana* Lamb.) (Malhotra and Khan 1980).

Results and Discussion

Examination of heterozygosities and number of alleles per locus for red, black, white and Norway spruce analyzed in our laboratory (Table 2) illustrate the range of values expected for northeastern and European spruce species. Heterozygosity for the 17 plot sample (492 trees) of red spruce from NH, VT, and NY averaged 9.1%, while that calculated from the red spruce provenance test is 7.8%. These values are very low for trees, and are lower than many plant species (Hamrick 1979). Examination of the provenance material for red and black spruce indicates that red spruce, at 7.8%, is only 38% as variable as black spruce (20.3%), with which it shares much of its habitat over its natural range, and is lower than white spruce (22.8%), another sympatric species. Red x black spruce hybrids are intermediate between the parent species in both heterozygosity estimates and number of alleles per locus. Both black and white spruce are sympatric with red spruce yet exhibit much greater genetic variability.

Electrophoretic analysis of Norway spruce for the same alleles resulted in an estimate of 1.6 alleles per locus, the same as red spruce sampled from NVS plots, but heterozygosity was greater at 15.7%. Thus, on the average, Norway spruce has the same number of alleles per locus as red spruce, but these alleles occur in heterozygous genotypic combinations more often. Estimates for values taken from the European literature are higher. This is probably due to a wider European geographic sample, but it should also be noted that these studies are based on fewer loci that are known to be highly variable. They may be overestimates and comparisons must be made with caution.

Genetic distance (Cavalli-Sforza and Edwards 1967) between red and black spruce is 0.220 based on the 14 loci examined in this study. Genetic distance among the 17 plots of red spruce averaged 0.099, a value indicating relatively low within-species differentiation. Five of 14 loci (AAT-1, G2D-1, 6PG-1, PGI-2, and UGPP) exhibited significant variation (5%) in gene frequencies, according to heterogeneity chi-square tests, across the 17 plot samples. Chi-square tests for deviation from the Hardy-Weinberg equilibrium revealed only 5 plots with any indication of non-random mating, and then only for one or two loci. Fixation indices (Wright 1978) were low, indicating that inbreeding levels are low in these plots. Since our evaluations are based on foliage, it should be pointed out that estimates of mating parameters do not reflect current conditions, but rather conditions that existed when zygote formation occurred 30 to 100 years ago. Heterozygosity levels and alleles per locus do reflect current population conditions, however.

The population statistics generated by electrophoresis are supported by growth and survival data from red spruce provenance tests in the Canadian Maritime provinces (Morgenstern et al. 1981; D.P. Fowler, Y.S. Park, A.G. Gordon, personal comunication) which indicate that the magnitude of provenance variation in height and mortality of red spruce is moderate.

There is a great deal of evidence in the air pollution literature which suggests a genetic-selection role for air pollution (*eg.* Houston 1976, Reinert *et al.* 1982). Berrang *et al.* (1986) present a convincing case for natural selection for ozone tolerance in trembling aspen *(Populus tremuloides* Michx.) from populations of naturally varying exposure levels. The level of genetic diversity appears to be related to air pollution sensitivity of Norway spruce phenotypes in natural stands. Bergmann and Scholz (1987) report that undamaged trees they judged to be tolerant to air pollutants in the Harz mountains of Germany have higher heterozygosity levels and may have more alleles per locus than do sensitive trees in the same stands. In an examination of Scots pine (*Pinus sylvestris* L.) families, Geburek *et al.* (1987) observed greater heterozygosity levels in SO_2 tolerant families and noted gene or genotypic frequency differences between sensitive and tolerant classes.

In consideration of the hypothesis that tree species with greater heterozygosity levels are better adapted to temporal and spatial variation in environmental stresses, red spruce does not appear to be a candidate for success in highly stressed environments. Since it is less heterozygous than its sympatric spruce associates, and Norway spruce, red spruce would not be expected to respond as well as these species to environmental stress, anthropogenic or otherwise.

Table 2.--Comparison of genetic diversity statistics for red, black, white and Norway spruce

Species	Populations	Loci	Alleles/locu	Heterozygosity	Reference
			Number	*Percent*	
Red spruce	17	14	1.6	9.1	1a
Red spruce	13	14	2.4	7.8	1b
Black spruce	15	14	3.0	20.3	1c
Red x black	1	14	1.7	14.3	1d
White spruce	15	14	2.8	22.8	1e
Norway spruce	2	14	1.6	15.4	1f
	20	6	2.5	----	2
	2	4	2.5	43.0	3

1a. Survey of NH, VT, and NY plots, UNH laboratory.

1b. Range-wide provenance test, UNH laboratory.

1c. Provenance test, UNH laboratory.

1d. Collection of 5 hybrid trees supplied by Petawawa National Forestry Institute, Ontario; run in UNH laboratory. Comparisons should be made with caution between of low numbers of trees.

1e. Progeny test from northeastern parents, UNH laboratory.

1f. Sixty trees from populations, UNH laboratory.

2. Bergman 1975.

3. Tigerstedt 1973.

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Comparison of Reproductive Fitness Between Two Fraser Fir Populations in the Southern Appalachians

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Abstract

During the spring of 1986 and 1987, and the fall of 1986, male and female strobili were collected from 10 mature Fraser fir (**Abies fraseri** *(Pursh) Poir.) trees at Mt. Mitchell, NC and Mt. Rogers, VA. During 1987, male strobili collected from Mt. Rogers produced significantly mature microsporangia and more pollen grains per strobilus than those from Mt. Mitchell. However, when values for 1986 and 1987 were averaged differences between locations were no longer significant. Pollen germination did not vary significantly by location for either year, but did vary within location for both years. Female strobili collected in 1986 did not differ with regard to the number of seed produced or total strobilus weight, but seeds produced at Mt. Mitchell were generally larger. Mr. Mitchell strobili contained more full seed, less insect-damaged seed, and seed exhibited higher germination rates than Mt. Rogers strobili.*

Introduction

The mature spruce-fir forest found at Mt. Mitchell, NC is apparently in a state of decline, while the same forest type found at Mt. Rogers, VA appears to be vigorous and healthy. One hypothesis proposed for this apparent difference in population structure is that the two populations differ in their reproductive fitness; and that air pollutants are somehow involved in modifying fecundity. The first step toward addressing this hypothesis is to determine if there are significant population differences present with regard to fecundity. This study was established to investigate and compare fecundity parameters of Fraser fir (**Abies fraseri** (Pursh) Poir.) such as pollen production, percent pollen germination, seed production and seed viability between the two populations.

Materials and Methods

Branches with male stroboli were collected from Mt. Mitchell and Mt. Rogers in late April and early May, 1986 and 1987. All material was promptly delivered to the laboratory and branches were placed in water, at room temperature, to promote further strobilus expansion. Some strobili were allowed to shed pollen, which was later used in germination tests, while other strobili were fixed just prior to pollen dispersal, in a 50% ethanol, 50% water mixture and stored at 2°C. The number of microsporangia per strobilus was determined from these fixed strobili by counting under a dissecting scope. Subsamples of 10 microsporangia per strobilus were used to estimate the number of pollen grains per microsporangium. The number of pollen grains per strobilus was determined from the product of the number of microsporangia per strobilus and the estimate of pollen grains per microsporangium. In 1986 10 genotypes at each location were sampled and 30 strobili per genotype analyzed. This procedure was modified in 1987 so that 15 genotypes (including the original 10) at each location were sampled and 20 strobili per genotype analyzed. Collections from each year resulted in the analysis of 300 strobili per location.

Five female strobili were collected from each of 10 Fraser fir genotypes at Mt. Mitchell and Mt. Rogers in mid-September, 1986. Each strobilus was individually bagged in paper, and allowed to air dry at room temperature in a storage facility on the Virginia Tech campus. Strobili were dissected and the seeds and scales separated, counted and weighed. Combination of seed and scale weights yielded total cone weight, and the total number of seeds divided by total seed weight yielded an average seed weight per strobilus.

Fifty seed from each strobilus were sent to the National Tree Seed Lab in Dry Branch, GA. USDA Forest Service personnel performed x-ray analysis on the seeds to determine percent full seeds and percent insect-damaged seeds. Following a 28-day stratification period, germination tests were conducted to determine seed viability.

Data for both male and female strobulis attributes were analyzed using standard analysis of variance techniques. Location differences were tested using genotype (location) as the error term since the genotypes are nested within the two locations.

Results

The number of microsporangia produced per male strobilus did not differ between Mt. Rogers and Mt. Mitchell in 1986, and Mt. Rogers strobili produced significantly more microsporangia than

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Mt. Mitchell in 1987 (Table 1). When values were averaged across both years Mr. Rogers was still highest but the difference was no longer significant. The amount of pollen produced per microsporangium was greatest at Mt. Mitchell in 1986 and then at Mt. Rogers in 1987 (Table 1). When values for both years were combined no location difference was present. More pollen per strobilus was produced at Mt. Mitchell in 1986 than at Mt. Rogers (Table 1). This pattern was reversed in 1987 and combination of data from both years showed no difference between locations. Pollen germination varied between 74 and 86%, and averaged 81.4% when averaged across both years (Table 2). No difference in percent pollen germination was present between locations for either year; but differences within locations, from one year to the next were present for both locations.

Total female strobilus weight and number of seed produced per female strobilus did not differ significantly between Mt. Mitchell and Mt. Rogers, but total and average seed weight per strobilus, were greater at Mt. Mitchell (Table 3).

Female strobili collected in 1986 from Mt. Mitchell contained 72.3% full seed versus 28.0% at Mt. Rogers (Table 4). Only 6.7% of Mt. Mitchell seed showed evidence of insect damage while nearly half of the seeds from Mt. Rogers were insect-damaged. Percent seed germination was significantly higher at Mt. Mitchell than at Mt. Rogers (8.12 and 0.04%, respectively).

Table 1.--Male strobilus attributes of Fraser fir populations at Mt. Mitchell, NC and Mt. Rogers, VA

Attribute	Year	Mt. Mitchell	Mt. Rogers	p-value
Number microsporangia per strobilus	1986	48.9	52.2	0.36
	1987	52.3	56.9	0.03
Mean for both years		50.6	54.6	0.07
Number pollen grains per microsporangium	1986	1148	868	0.07
	1987	927	1128	0.06
Mean for both years		1038	998	0.69
Number pollen grains per strobilus	1986	57181	45398	0.22
	1987	48788	65112	0.01
Mean for both years		52985	55255	0.70

Table 2.-Pollen germination percentage of Fraser fit populations at Mt. Mitchell, NC and Mt. Rogers, VA

Collection year	Mt. Rogers	Mt. Mitchell	p-value
	---------*Percent*---------		
1986	*74.5*[a]	*82.1*	*(0.11)*
1987	*82.5*	*85.9*	*(0.42)*
p-value	(0.02)	(0.005)	
Mean both years	78.7	84.0	(0.09)

[a]Mean of nine genotypes. All other means consist of ten genotypes.

Table 3.--Female strobilus attributes of Fraser fir populations at Mt. Mitchell, NC and Mt. Rogers, VA samples in 1986

Location	No. seed per strobilus	Total seed weight per strobilus	Average strobilus weight	Total strobilus weight
		g	mg	g
Mt. Mitchell	251	1.83	7.0	5.75
Mt. Rogers	268	1.13	4.1	5.53
p-value	(0.42)	(0.005)	(0.0001)	(0.76)

Table 4.--Seed attributes of Fraser fir populations at Mt. Mitchell, NC and Mt. Rogers, VA, sampled in 1986

Location	Full seed per per strobilus	Insect-damaged seed per strobilus	Germination
	-----------------------	*Percent*	-----------------------
Mt. Mitchell	72.3	6.7	8.12
Mt. Rogers	28.0	48.9	0.04
p-value	(0.0001)	(0.0001)	(0.01)

Discussion

There was a tendency for the number of microsporangia produced per strobilus to be greater at Mt. Rogers than at Mt. Mitchell but this difference was not consistently significant at $p < 0.05$ (Table 1). Location differences in pollen production per microsporangium and pollen production per strobilus were likely present for both 1986 and 1987, but patterns were reversed from one year to the next. In all cases, differences between years were more significant than differences between locations and no location difference was evident when data from both years were combined. Pollen germination percentage did not differ by location, but did differ by year (Table 2). The combination of these results indicates that although a slight difference in male strobilus configuration may be present between Mt. Mitchell and Mt. Rogers, no clear difference exists with regard to pollen production or viability.

The configuration of female strobili was remarkably similar at Mt. Mitchell and Mt. Rogers in 1986 (Table 3). No differences were found in the number of seed produced per strobilus or the average total strobilus weight. Significant differences were found, however, in seed quality and viability. Mt. Mitchell strobili produced significantly larger seeds (Table 3), more full seeds, less insect-damaged seeds, and seeds with a higher germination percentage (Table 4). These results indicate that a difference in seed quality was present between the two locations in 1986.

Conclusions

No evidence was found in this study to indicate that consistent and potentially long-term differences in either pollen production or viability exist between the Fraser fir populations of Mt. Mitchell, NC and Mt. Rogers, VA. Mt. Mitchell trees apparently produced more pollen per strobilus in 1986 but the trend was largely reversed in 1987, with greater pollen production per strobilus occurring at Mt. Rogers. This reversal should result in cautious interpretation of the single year of data for female strobilus attributes. Our data show that Mt. Mitchell produced significantly more viable seed in 1986, but it is unclear whether this trend will be continue in the future.

Seed Quality of Red Spruce and Fraser Fir in High-Elevation Stands

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Abstract

Preliminary data on seed yield, seed weight, embryo length, germination, seedling weight, leachate conductivity, and response to accelerated aging have been collected for samples of red spruce (Picea rubens Sarg.) from Mt. Moosilauke, Mt. Rogers, Clingman's Dome, and Roan Mt. Data for some of these tests are in hand for Fraser fir (Abies fraseri (Pursh) Poir.) from the latter two sites. Filled seed per cone values for red spruce were very low: 1.3 to 4.3, but there is no evidence as yet that atmospheric deposition is responsible. Reports in the literature, while not specifically for red spruce, suggest that these yields may be normal for high-elevation sites. Other seed parameters and germination data suggest that seed quality of these collections is equal to, and in one case better than, seed quality of the check lots. Most measurements are not complete, and another collection is scheduled in 1987. At this time there is no evidence for decreased seed quality of red spruce and Fraser fir from these sites.

Successful natural regeneration is a critical factor for the continued presence of spruce-fir forests of the eastern United States. Even as the conditions responsible for the decline of these species at high elevations are identified and mitigated, healthy reproduction must be present to replace the older dying trees. The objective of our study is to determine if the quality of seed from declining stands/trees is equal to that of seeds from stands/trees with little or no damage symptoms.

Poor cone crops on the six major research sites of the Spruce-Fir Cooperative resulted in no seeds for our study in 1985 and only a partial collection in 1986. The data presented here are summaries of preliminary data. Complete analyses await input from another Research Cooperative study that is utilizing seeds from the same study trees.

Materials and Methods

Cones of red spruce *(Picea rubens Sarg.)*, balsam fir *(Abies balsamea* (L.) Mill.) and Fraser fir *(A. fraseri* (Pursh) Poir.) were collected in 1986 from four of the six research sites (table 1). Collections were organized by personnel of the Northeastern Forest Experiment Station (USDA, Forest Service), Durham, NH, for all Cooperative projects that needed seeds or seedlings for their research. Most collections were made by a University of Vermont-U.S. Forest Service team.

Several samples of low-elevation red spruce seeds were obtained for use as check lots. These samples are from Pittstow Township, Maine; Chatham, New Hampshire; and Waterville Valley, New Hampshire. A single check lot of Fraser fir was obtained from the seed orchard of the North Carolina Dept. of Natural Resources. The scion material in this orchard is from Mt. Mitchell in western North Carolina.

Table 1.--Sites of 1986 collections

Site	Latitude	Elevation *M*	Approximate collection date
Mt. Moosilauke, NH	44° 00'	1,170-1,260	Early October
Clingman's Dome, TN	35° 30'	1,680-1,920	Mid-September
Roan Mt., NC	36° 00'	1,830-1,890	Mid-September
Mt. Rogers, VA	36° 30'	1,600-1,650	Late September

Single-tree collections were made from 35 trees of each species at each site (red spruce and balsam fir at Mt. Moosilauke; red spruce and Fraser fir at the three southern sites). Within a few days of collection, the cones were shipped in paper bags to the Forestry Sciences Laboratory in Starkville, Mississippi. Red spruce cones were placed in cloth bags and dried outdoors on wooden tables. Alternate wetting by rain and subsequent drying promotes cone opening. If no rain occurred for 5 days, the cone bags were wet artificially. After 3 or 4 weeks the cones were moved inside for final drying on screen racks at about 25°C and later in ovens at 30° to 35°C.

All fir cones were left on the indoor screen racks for 3 to 4 weeks, then broken apart by hand. Seeds were screened from all debris, dewinged by hand, and cleaned again with hand screens and pneumatic seed cleaners (Stults and South Dakota blowers). Red spruce seeds were dewinged by hand and cleaned with screens and the Stults blower. Most empty seeds were removed from the sample lots with the Stults blower set at 1.00 to 1.10 lbs. static pressure for red spruce and 0.90 to .95 lbs. for Fraser fir. Additional sorting for Fraser fir was done from radiographs taken with a Faxitron 804 on AA Kodak film. Exposures were 15 or 20 KVP, 3mA., and 60 seconds. All seeds were stored at 3° C in air-tight polyethylene bottles or bags after cleaning was completed.

Because seed yields were unexpectedly low, the tests for seed quality had to be scaled down considerably to only 10 trees per site for red spruce and 17 trees per site for Fraser fir. There were insufficient filled balsam fir seeds for any tests. Procedures were carried out as follows:

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(1) **1000-seed weight** - Four replications of 25 filled seeds each were selected from each tree with the aid of radiographs. Each sample was weighed on a PC Mettler Balance 4000 to the nearest mg.

(2) **embryo length** - A nondestructive method of embryo length measurement was done by viewing seed radiographs in a binocular microscope equipped with a micrometer and light below the stage of the microscope. The radiograph corners were numbered 1, 2, 3 and 4 and an imaginary quadrant division was outlined. Ten embryos were randomly chosen and measured in each quadrant to the nearest millimeter.

(3) **germination test** - Seeds were tested according to official test prescriptions (Association of Official Seed Analysts 1981). Four samples of 25 seeds each were incubated on white germination blotters in a Stults water-curtain germinator with a temperature regime of 8 hours light at 30°C and 16 hours dark at 20°. Germination was counted three times a week for 21 days. Ungerminated seeds were cut to determine the numbers of apparently dormant and rotten seeds. Fraser fir seeds received 28 days of moist stratification at 3°C before testing. Red spruce requires no pretreatment. As seedlings were scored as germinated, they were left on the blotters for seedling weight measurements.

(4) **seedling weight** - At the end of the 21-day germination test, the seedlings were carefully removed from the blotters to determine fresh weight to the nearest mg. Seed coat and gametophyte tissues were removed before weighing.

(5) **electrolyte leakage** - Electrolyte leakage was measured in the seed leachate of 25-seed samples with an ASAC-1000 Automatic Seed Analyzer (Bonner and Vozzo 1986). Soak periods were 24 hours, and meter voltages were 4 V. for both species.

(6) **accelerated aging** - Samples of 25 seeds each of red spruce were incubated for up to 8 days at 40 ± 1°C in a Stults accelerated aging cabinet, then germinated with the same procedures used in the germination test.

Results

Seed yields for red spruce were very low (table 2). Mt. Rogers cones were best with 4.3 filled seeds per cone, while cones from the other two southern sites were much lower (1.3 seeds per cone). General seed collection data from many sources (Safford 1974) suggest that red spruce normally yields 35 seeds per cone. Low elevation collections in Ontario have averaged 25 filled seeds per cone (B.S.P. Wang, personal communication). Yield data are not available from our check lots, as they were acquired as cleaned seeds.

Estimated yields of filled seeds from Fraser fir cones were similar for Clingman's Dome and Roan Mt. (53 and 48 per cone), the only collections that yielded filled seeds. Seeds from Mt. Rogers looked good, but were less than one percent filled, according to cutting tests.

Seed weight, embryo length, and seedling fresh weight at 21 days suggest little at this time (table 3). When all individual tree growth and decline data are available, regression analysis will be used to relate these parameters to seed and seedlings characteristics. One point of interest is the smaller size of red spruce seeds from Mt. Moosilauke as compared to seeds from the three southern sites. Such differences are very common in seed collections from latitudinal extremes.

Table 2.--Yields of filled seeds in 1986 collections of red spruce and Fraser fir (standard deviations are in parentheses)

Site	Number of trees	Mean no. cones/tree	Mean no. seeds/cone	Range of seeds/cone
Red spruce				
Mt. Moosilauke	21	50 (44)	2.4 (1.2)	0.7-4.8
Clingman's Dome	28	124 (84)	1.3 (0.9)	0.1-3.9
Roan Mt.	31	94 (78)	1.3 (1.1)	0.2-4.8
Mt. Rogers	26	70 (46)	4.3 (3.0)	0.6-13.3
Fraser fir				
Clingman's Dome	24	55 (45)	53 (33)	8.6-138.3
Roan Mt.	14	26 (6)	48 (47)	4.2-144.1

Table 3.--Mean seed weight, embryo length, and seedling fresh weight at 21 days for red spruce and Fraser fir (standard deviations are in parentheses)

Site	Number of trees	1000-seed weight	Embryo length	Seedling fresh weight
		g	*mm*	*mg*
Red spruce				
Mt. Moosilauke	10	2.8 (0.2)	2.0 (0.1)	11.1 (1.5)
Clingman's Dome	10	4.0 (0.5)	2.4 (0.1)	11.7 (2.5)
Roan Mt.	10	4.1 (0.5)	2.4 (0.1)	15.1 (2.3)
Mt. Rogers	10	4.0 (0.6)	2.4 (0.1)	14.4 (3.3)
Fraser fir				
Clingman's Dome	17	10.4 (1.3)	4.3 (0.2)	34.7 (6.1)
Roan Mt.	17	10.0 (1.2)	4.3 (0.2)	36.3 (6.9)

Results of the germination tests (figure 1) suggest that seed quality is good. Further evidence for good seed quality in these high-elevation collections of red spruce comes from the leachate conductivity and accelerated aging data (table 4, figure 2). Leachate conductivity for all samples ranged from 73 to 97 μA, very close to readings on three low-elevation check lots. Germination of these same samples gave excellent results (table 4). Accelerated aging treatments of bulked lots from each of the four sites showed deterioration patterns very similar to those of the low elevation check lots (figure 2). In fact,the high-elevation seeds appear to have survived the aging treatments better than the check lot seeds.

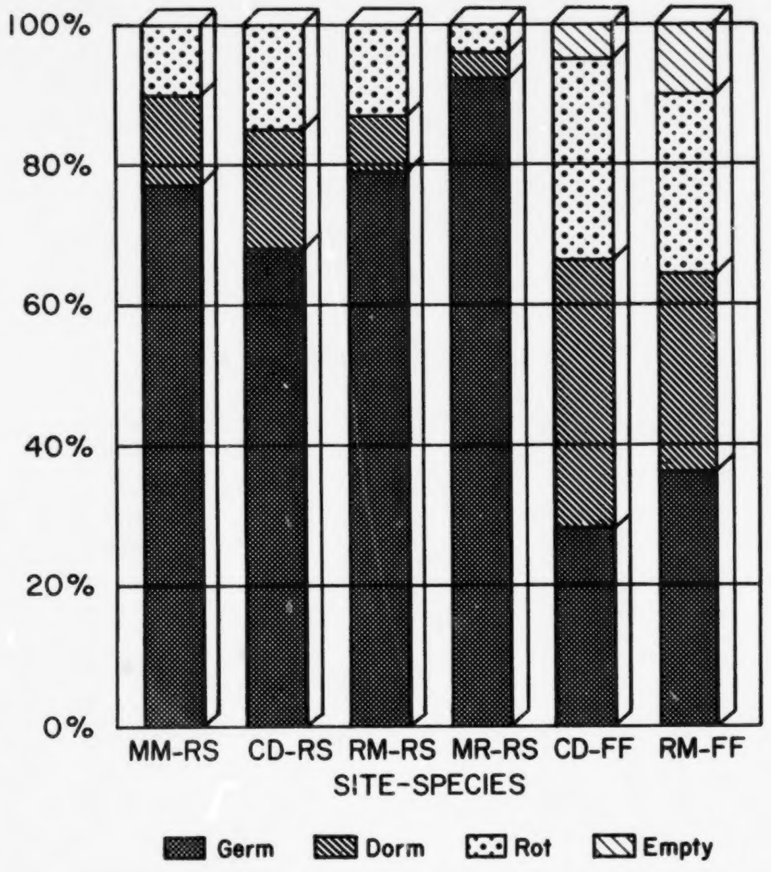

Figure 1.--Germination test means for red spruce (RS) and Fraser fir (FF) from four research sites: Mt. Moosilauke (MM), Clingman's dome (CD), Roan Mt. (RM), and Mt. Rogers (MR). Germ = % germination; Dorm = % ungerminated good (dormant) seeds; Rot = % rotten seeds; Empty = % empty seeds.

Table 4.--Leachate conductivity and germination results for red spruce study sites and check lots

Source	Mean conductivity	Percent germination
	microamp	
Study sites		
Mt. Moosilauke	86	93
Clingman's Dome	90	86
Roan Mt.	87	90
Mt. Rogers	80	94
Check lots		
Pittstow Twnp., ME	86	94
Chatham, NH	91	86
Waterville Valley, NH	96	67

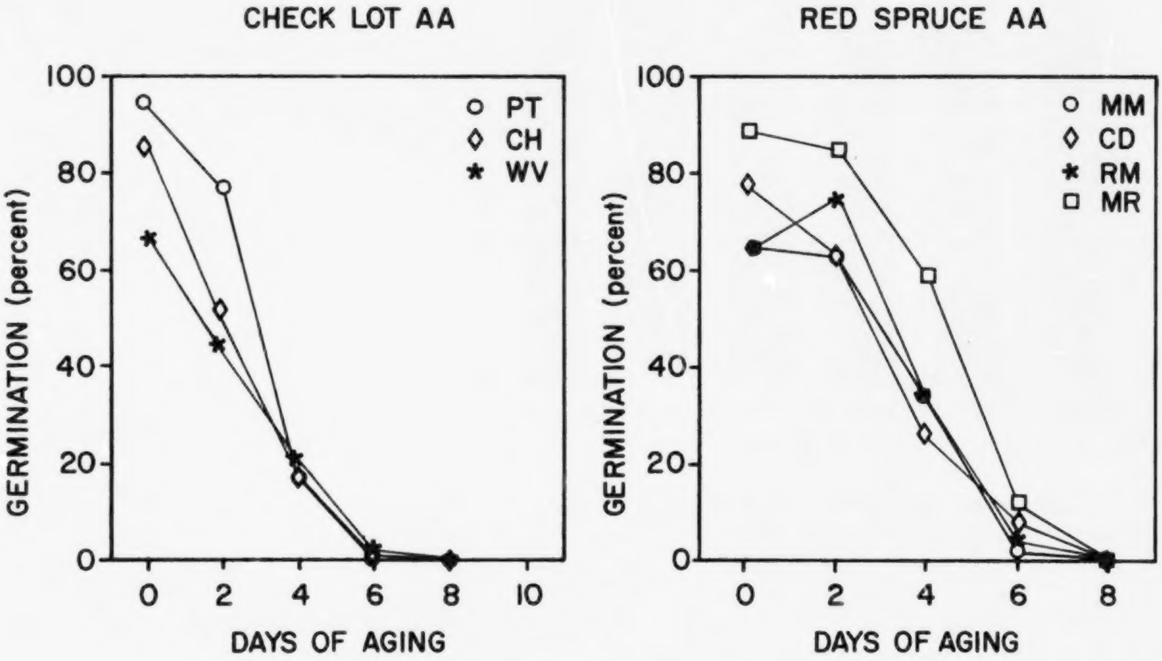

Figure 2.--Germination of red spruce following accelerated aging treatments. (A) Research site samples: MM(Mt. Moosilauke), CD(Clingman's Dome), RM(Roan Mt.), MR(Mt. Rogers). (B) Check lots: PT(Pittstow Twnp.), CH(Chatham, NH), WV(Waterville Valley, NH).

Discussion

At this stage of the study there is no evidence of poor seed quality from these four study sites: Mt. Moosilauke, Clingman's Dome, Roan Mt., and Mt. Rogers. These are only preliminary results, however, and most test results are not yet available, especially for the firs. We have Fraser fir data from only two sites, and no balsam fir data at present. A second year's collections are planned from these sites.

Analyses of individual tree parameters are also yet to be done. These require data from other researchers in the Cooperative, and all measurement have not been completed. Comparisons with check lots from lower elevations and other sources indicate very low seed per cone values for the high-elevation red spruce. We have not yet found any seed yield data for high-elevation red spruce from past years, but smaller seeds from higher elevations and northern latitudes have been previously reported for *Picea* (Safford 1974). Smaller and fewer seeds are generally expected from trees in less favorable environments (Krugman et al. 1974), so a direct relationship between lower seed yields and atmospheric deposition cannot be assumed, even though this effect has been reported on *P. abies* in East Germany (Piesnack 1986). We are continuing the search for older records of seed yield from high-elevation sites.

A likely cause of the low seed yields for red spruce is poor pollination at the high-elevation sites. Studies on *P. engelmannii* show that a major cause of low seed set is inadequate pollination (Owens et al. 1987). Similar studies have not been done on red spruce, but conelet receptivity sequences are similar in *P. glauca* in Ontario (Ho 1984) and *P. mariana* in New Brunswick (Caron 1986).

Conclusions

More collections and tests are forthcoming, but the results to date suggest that seed quality was very good in the sampled populations in 1986. Seed yield (filled seeds per cone) was surprisingly low for red spruce, but this condition may be normal for high-elevation stands.

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Fungal Flora In Spruce-Fir Forests of the FRG and Its Possible Relation to Air Pollution

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When considering the so-called "Waldsterben" in spruce and fir forests of the Federal Republic of Germany, it is justified to ask about the influence or role of microorganisms, in this case particularly fungi.

Tree diseases caused by fungi have been known in general long before air pollutant damage was discovered. Even if a balance exists between pathogens and their host in most cases, we know some severe diseases in which the pathogen does not respect the balance and the host is endangered. Dutch Elm Disease or Chestnut Blight can serve as examples.

This paper describes the fungal flora of spruce and fir in Europe, first taking the real parasites into consideration, secondly the weak parasites and, finally, other fungi colonizing spruce needles without causing symptoms.

The following species belong to the classical agents of needle diseases on spruce in Europe: *Lophodermium macrosporum, Lophodermium filiforme, Chrysomyxa abietis* and *Chrysomyxa rhododendri*.

Lophodermium macrosporum is an ascomycete which attacks only the last complete needles, causing yellow discoloration and premature needle cast, but only on several individual needles. The disease appears commonly in young stands of spruce, especially in the southern part of Germany, without causing severe damage. Similar symptoms are caused by *Lophodermium filiforme,* known also in the United States as the agent of a severe needle cast in spruce (Darker). This species has been observed recently in Europe. Some authors view both fungi as identical. *Chrysomyxa abietis* and *Chrysomyxa rhododendri* belong to the commonly occurring rust fungi on spruce needles, leading to the loss of younger needle sets. Normally, rust fungi are characterized by two alternate host-species. In the case of *Chrysomyxa rhododendri* the fungus, i.e. the disease, is restricted to mountainous areas where both hosts, spruce and Rhododendron, occur. This is not so in the case of *Chrysomyxa abietis,* where infections from tree to tree (microcycle) can be observed.

In respect to the so-called "Waldsterben" on spruce in Germany, the symptoms of the classical parasites such as *Lophodermium macrosporum* or *Chrysomyxa* spp. are not similar to those of decline. The "new" forest diseases are characterized by crown-thinning, which is due to the casting of older needles from the inner part of the crown of spruce. In this case, the above mentioned parasites could not be detected.

But there is another group of ascomycetes and imperfect fungi which colonize damaged or prematurely aged needles. This group includes weak parasites as well as saprophytes. Sometimes it is hard to prove whether a fungus has a more or less parasitic or saprophytic nature.

In order to record such species, brown needles from different localities affected by air pollution were collected from the crown and investigated in the laboratory. The species and their frequency are listed below in (Table 1).

Table 1: Fungal species or genera isolated from brown needles

	CYTOSPORA ABIETIS	0.1%
	DISCULA PINICOLA	
	EPICOCCUM PURPURASCENS	0.2%
	HYALOSCYPHA STEVENSONII	
X	LOPHODERMIUM PICEAE	43.0%
X	LOPHODERMIUM FILIFORME	
X	LOPHODERMIUM MACROSPORUM	
X	PEZICULA LIVIDA	0.1%
	PHOMOPSIS CONORUM	6.8%
X	PHOMOPSIS OCCULTA	
X	RHIZOSPHAERA KALKHOFFII	15.1%
	RHIZOSPHAERA PINI	14.0%
	SIROCOCCUS STROBILINUS	
	STACHYBOTRIS SP.	
X	THYSANOPHORA PENICILLIOIDES	3.7%
X	TIAROSPORELLA CF. PARCA	
	UNDETERMINATED FUNGI	6.0%
	STERILE NEEDLES	29.0%

The Table shows that brown, dying needles are colonized by many species, of which the most frequent are *Lophodermium piceae, Rhizosphaera kalkhoffii* and *Rh. pini*. A remarkable observation is that not all needles contain fungi or other microorganisms. This allows the conclusion that the true cause of needle-cast could have an abiotic aspect. Adverse climatic conditions as well as effects of air pollution must therefore be taken into consideration.

Also a part of the "new" forest diseases of spruce is the yellow discoloration of older needles occurring mostly in the higher mountains. Needles of this symptom-complex were also examined in the laboratory. Parallel to this research, a control was done with green needles of spruce from different areas of Germany. The results of these control experiments are documented (Table 2).

The occurrence of fungal mycelium in green needles may come as a surprise, since the tissue was viewed as healthy up to the

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present. Recently, it has been demonstrated that many plants contain various fungi without showing symptoms. These fungi are now called endophytes. One of the first publications about this group of organisms appeared in the United States, done by Carroll.

Table 2. Fungal species or genera isolated from green needles

LOPHODERMIUM PICEAE	43.0%
SICROCOCCUS MYRTILLI	1.8%
SIROCOCCUS STROBILINUS	0.8%
PEZICULA LIVIDA	0.6%
other species (41!)	6.8%
sterile needles	48.0%

Our research yielded over 50 different species of fungi, mostly ascomycetes, in part as imperfect stages. Only a few of these are known as spruce-inhabiting fungi, for instance *Lophodermium piceae*, which is capable of existing for many years in green needles until the vitality of the needle is reduced by a large range of possible factors. The relationship between these endophytic fungi and the needle is not yet clear. A mutual advantage is possible, as is the case in mycorrhizal fungi. We assume that the existence of endophytes is part of an old association between organisms and not related to man-made influences. Definitely, this group is also not responsible for the so-called "new symptoms" in spruce.

We suspect that root-inhabiting fungi not forming mycorrhiza play a more important role in the recent development of forest decline in Germany. Investigations are in full progress, but until now no conclusive results can be presented.

Contrary to the fungal flora of spruce, the needle-inhabiting organisms of fir have been studied less intensively by our group. What we know is that fir accommodates a very low number of needle parasites and endophytes. The most important species, including weak parasites, are presented in the following: *Hypodermella nervisequia*, *Herpotrichia parasitica*, *Pucciniastrum epilobii*, *Rhizosphaera oudemansii* and *Cytospora friesii*. The last two species occur only after the needle has been damaged by frost.

Virus Diseases in Forest Trees

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Viruses are widespread pathogens in forests, contaminating trees, shrubs, soil and water in almost all parts of West Germany. About 30% of samples taken from leaf/needle, roots, soil or streams, water pools and lakes were virus-positive. There is no question that viruses are important in many broad-leaf tree species as accompanying or - at least - predisposing factors of the decline syndrome; for instance in elm, ash, birch, poplar and probably in oak and beech. In birch and beech, strains of Cherry leaf roll virus are important, in oak strains of TMV, or other *Tobamo*-viruses.

Different groups of scientists in Germany found viruses or virus-like particles in conifers, for instance in fir, spruce and pine, but so far no one could demonstrate that they cause any severe symptom. Spherical particles have been demonstrated in fir in the Black Forest by Frenzel, University of Hohenheim, (similar to *Caulimo*-Virus). In spruce in the Bavarian Forest and Fichtel - gebirge, viruses of the *Poty*-Virus group and structures similar to *Clostero*-viruses were isolated and demonstrated by Nienhaus, Bonn and Ebrahim-Nesbat, University of Göttingen. Roots of spruce growing in Rhineland-Westfalia were found to be contaminated with *Potex*-viruses, others with Tobacco necrosis virus. In water of spruce and pine sites, or with beech and oak, identical *Potex*-viruses isolated from root and soil samples were found. Also, some *Tombus*-viruses, for instance the Italian Carnation rinspot virus were discovered, so far never found in forests or rivers near Bonn.

Nevertheless, there is no indication, so far, that viruses play a significant role in decline of conifers. Mycoplasma-like organisms and Rickettsia-like bacteria could not be detected in forest trees, except MLO in poplar and RLB in larch, which is responsible for a severe decline of the tree in several areas of West Germany.

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Spruce Beetle Survey on Red Spruce in New York, Vermont, New Hampshire, and Western Maine

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Abstract

A 1986 survey assessed spruce beetle's association with heavy mortality areas of spruce-fir slope type in northern New England. Spruce beetle attacks were found on 30 percent of the Adirondacks spruce trees surveyed and were present on 28 percent of the area surveyed. Two-thirds of all standing, dead spruce trees in the Adirondacks had spruce beetle attacks. Furthermore the infestation appears to be intensifying on 70-80 percent of the infested areas. In comparison, spruce beetle attacks were rare or absent on spruce trees surveyed in Vermont, New Hampshire or Maine. Why spruce beetle is most active in the Adirondacks is discussed.

In many areas experiencing spruce tree mortality, the beetle is not active. Future work should focus on other potential mortality agents in these areas as well as spruce beetle biology, impact and management in the northeastern United States.

Introduction

Extensive tree mortality is reported in the spruce-fir forests in the northeastern United States (Weiss and others, 1985). More than 30 percent of the standing spruce and fir are dead on about 300,000 acres in the Adirondacks of New York, Vermont and New Hampshire. Surveys by state agencies and Forest Pest Management (FPM) indicate that spruce-fir mortality is not a new phenomenon and many known biological mortality agents are present in areas experiencing decline and morality (Weiss and others, 1985). Field observations in 1984 and 1985 found spruce beetle (*Dendroctonus rufipennis* Kirby) often associated with heavy mortality areas.

The spruce beetle activity observed in 1984-85 and its history as a major mortality agent generated interest to determine its current role in the spruce decline. As a result, a cooperative survey was carried out in 1986 with these objectives:

1. to determine the proportion of heavy mortality area in spruce-fir slope type where spruce beetle was a significant mortality agent;
2. to determine the proportion of dead and declining spruce attacked by the spruce beetle;
3. to determine the status and trend of the spruce beetle infestation.

Survey Design

The survey was conducted in the Adirondacks of New York, Vermont including the Green Mountain National Forest, New Hampshire including the White Mountain National Forest, and western Maine (Miller-Weeks and others, 1987). These regions include spruce-fir type not infested by spruce budworm (*Choristoneura fumiferana* (Clemens)) within the last ten years.

Color infrared aerial photography at a scale of 1:24,000 was acquired in 1985 and used to define survey areas in New York, Vermont and New Hampshire.

The photography was stratified into several spruce-fir cover types and mortality classes (Ciesla, 1984). The spruce-fir slope type (greater than 50 percent crown cover in spruce-fir) with heavy tree mortality (greater than 30 percent of standing spruce-fir dead) was selected to survey for spruce beetle. In western Maine recent aerial photography was not available, and sketchmapping was used to select the survey areas. The delineated areas (polygons) were ranked into three size classes: less than 100 acres; 100-500 acres; and greater than 500 acres. Polygons were randomly selected and examined for beetle activity within each region and size class.

A total of 39 polygons representing 35,504 acres were sampled: 15 in New Hampshire, 11 in Maine, 11 in New York and 2 in Vermont. Within each selected polygon, clusters of three BAF 20 prism points were randomly located: Polygons smaller than 100 acres had two clusters; 100-500 acre polygons had three clusters; and polygons greater than 500 acres had four clusters and were divided into subunits based on drainage or ridge systems. A total of 117 clusters were sampled: 45 in New Hampshire, 36 in Maine, 32 in New York and 4 in Vermont. Of the 351 prism points examined, 136 were in New Hampshire, 108 in Maine, 95 in New York and 12 in Vermont.

Data Collection and Analysis

Site, stand, and individual tree data was recorded at each prism point. Site and stand information included elevation, aspect, slope, drainage, soil depth, crown closure, and stand age. For all "in" trees data collected included: species, dbh, crown position, and crown condition. Spruce and balsam fir trees were classified as live, dead, standing or windthrown. In addition, for spruce and balsam fir, spruce trees were also rated for spruce beetle attack and the year of attack. Altogether 841 spruce trees were examined: 341 in New Hampshire, 247 in Maine, 283 in New York and 15 in Vermont.

Results

Spruce beetle-attacked trees were common on prism points in New York's Adirondacks, absent in western Maine and Vermont and only one tree was found attacked in New Hampshire. In the Adirondacks, spruce beetle attacks were found in 28 percent of

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the prism points. These prism points averaged 10 attacked trees per acre. About 5 percent of the infested area had less than 10 trees per acre attacked; 21 percent of the area had 11-20 trees per acre attacked; and 2 percent of the area had more than 20 trees per acre attacked. In New Hampshire, only one prism point spruce tree was attacked by the spruce beetle.

In the Adirondacks, 30.2 percent of all spruce trees in prism points showed signs of beetle attack (Table 1). About 65 percent of standing, dead trees had beetle attack but only 8 percent of standing, live trees were attacked. Spruce beetle attacked the only recently windthrown tree found (100 percent) compared to 29 percent of the old, windthrown spruce.

Table 1.--Distribution of spruce beetle attacks in the Adirondacks of New York among the spruce trees examined during the 1986 spruce beetle survey.

Tree condition class	**Number of spruce trees**	**Percent of all spruce**	**Spruce beetle attacked trees**	
			Number	*Percent*
Standing				
Live	137	57.6	11	8.0
Dead	86	36.1	56	65.1
All Standing	223	93.7	67	30.0
Windthrown				
Green	1	0.4	1	100.0
Old	14	5.9	4	28.6
All Windthrown	15	6.3	5	33.3
Total	238	---	72	30.2

The average spruce dbh in the Adirondacks was 14 inches compared to 10 inches in Maine and New Hampshire and 8 inches in Vermont. In the Adirondacks, the average dbh of beetle-attacked trees was 18 inches compared to live spruce that averaged 13 inches dbh (Figure 1).

Two methods were used to estimate spruce beetle trends. The first method using 1985 compared to 1986 attacks shows that on 82.6 percent of the infested area beetle attacks increased and in 17.4 percent of the area beetle attacks decreased. The second method using the ratio of attacked vs. unattacked trees indicates that attacks are increasing in 69.1 percent of the infested area, static on about 0.9 percent, and decreasing on 30 percent of the infested area.

Discussion

The spruce beetle is a significant mortality factor in spruce-fir slope type, heavy mortality areas of the Adironbacks. About 28 percent of the area is infested with the spruce beetle. Infested areas averaged about 10 beetle-attacked trees per acre. About 10 percent of the standing, uninfested trees were attacked in 1986.

The reported spruce beetle preference for larger trees (greater than 10 inches dbh) may explain why spruce beetle is common in the Adirondacks. Beetle attacks were predominantly in larger spruce trees (Figure 1). No beetle attacks were found on trees smaller than 11 inches dbh. Most live spruce basal area without beetle attack is in trees under 12 inches dbh. Beetle-attacked basal area increases between 11 and 17 inches dbh and most spruce trees above 17 inches show beetle attack signs (Figure 1).

The infestation trend was increasing whether 1986 attacks were compared to 1985 attacks or all beetle-attacked trees were compared with unattacked trees. The trend suggests increased beetle activity and spruce beetle-caused tree mortality.

Spruce beetle attacks were not found in prism points in Vermont and western Maine. Only one spruce beetle-attacked tree was found in New Hampshire prism points. Although active spruce beetle outbreaks are present in each state, other factors appear to be responsible for the mortality mapped in 1985.

Several factors may influence identification of spruce beetle attacks. Trees frequently had heavy woodpecker activity on the bole in the crown. Usually woodpeckers are good indicators of bark beetle activity. However, if the tree is killed by beetle attacks above the observer's reach, the bark beetle's identity cannot be determined.

The literature has little information on spruce beetle biology, outbreak development and control in the East (Hopkins, 1901). The current Adirondacks outbreak and the threat to other areas with big spruce trees presents an opportunity to better understand spruce beetle biology, outbreak behavior and management.

In conclusion, the spruce beetle is a significant mortality factor in about one third of the spruce-fir slope type, heavy mortality area in the Adirondacks. However, most spruce mortality is not explained by spruce beetle activity. Further work is needed: 1) to identify what factor(s) caused or is causing spruce and balsam fir mortality in areas where spruce beetle is not present; and 2) to learn the biology, epidemiology and management of the spruce beetle in the northeastern United States.

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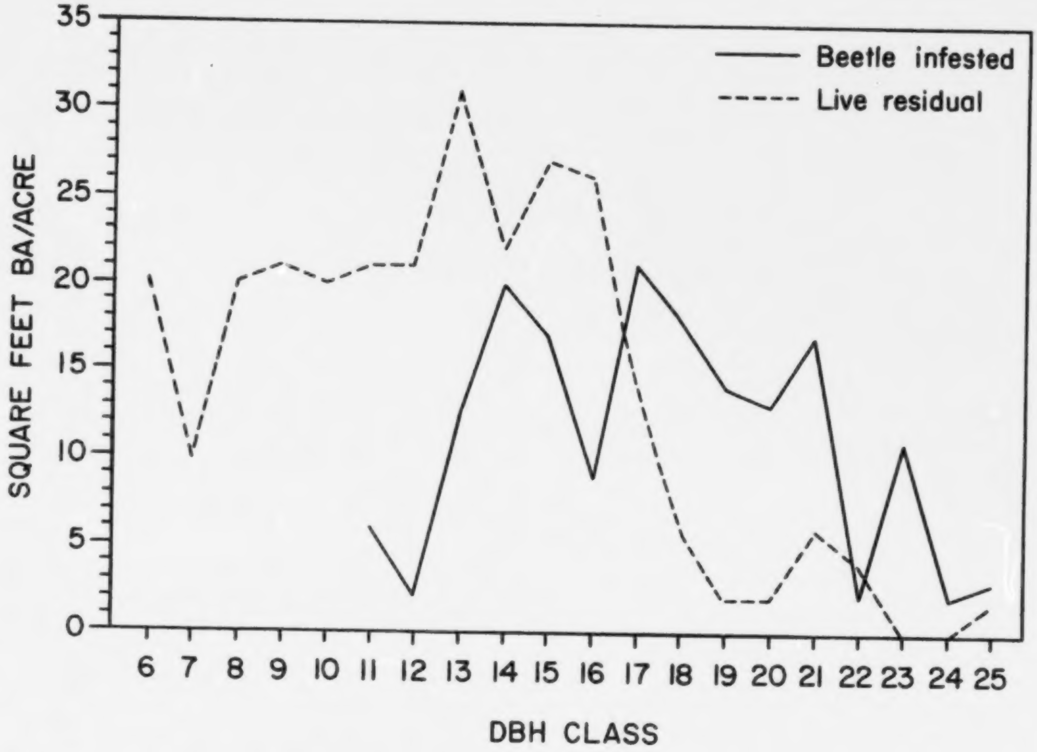

Figure 1.--Basal area by dbh classes for dead, beetle-infested and live, residual Adirondacks spruce in the 1986 survey.

Eastern Dwarf Mistletoe Survey on Red Spruce in New York, Vermont, New Hampshire and Western Maine

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Abstract

A 1986 survey assessed eastern dwarf mistletoe's association with heavy mortality areas of spruce-fir slope type in northern New England. New York and New Hampshire had infested spruce trees on over 25 percent of the area surveyed, and more than 20 trees per acre were infected on 80 percent of the affected areas. In contrast, Vermont and Maine had infected trees on 18 and 3 percent of the survey area respectively, and less than 10 trees per acre were infected on 88 percent of the affected areas. In general, both live and dead trees were lightly infected in each state.

Although eastern dwarf mistletoe is associated with spruce decline in the northeast, it does not appear to be a significant mortality agent. Eastern dwarf mistletoe was not observed in many areas experiencing spruce-fir decline. Future work should focus on other potential mortality agents as well as better defining eastern dwarf mistletoe's impact and management in the northeastern United States.

Introduction

Extensive tree mortality is reported in the spruce-fir forests in the northeastern United States (Weiss and others, 1985). More than 30 percent of the standing spruce and fir are dead on about 300,000 acres in the Adirondacks of New York, Vermont and New Hampshire. Surveys by state agencies and Forest Pest Management (FPM) indicate that spruce-fir mortality is not a new phenomenon and many known biological mortality agents are present in areas experiencing decline and mortality. Hawksworth and Shigo (1980) found eastern dwarf mistletoe (*Arceuthobium pusillum* Peck) causing growth loss, degrade and tree mortality in red spruce (*Picea rubens* Sarg.) stands on the White Mountain National Forest in New Hampshire. In 1984 and 1985, eastern dwarf mistletoe was observed in heavy mortality areas of spruce-fir stands in New York's Adirondack Mountains and New Hampshire's White Mountains.

The recent observations of dwarf mistletoe in the northeast and its history as a potential mortality agent have generated interest in its current role in causing spruce mortality. As a result, a cooperative survey was carried out between state and federal agencies to determine: 1) the proportion of heavy spruce mortality area where eastern dwarf mistletoe infection levels may be adversely impacting red spruce; 2) the proportion of live, declining and dead spruce infected by eastern dwarf mistletoe.

Survey Design

The survey was conducted in the Adirondacks of New York, Vermont including the Green Mountain National Forest, New Hampshire including the White Mountain National Forest, and western Maine (Miller-Weeks and others, 1987). These regions include spruce-fir type not infested by spruce budworm (*Choristoneura fumiferana* (Clemens)) within the last ten years.

Color infrared aerial photography at a scale of 1:24,000 was acquired in 1985 and used to define survey areas in New York, Vermont and New Hampshire. The photography was stratified into several spruce-fir cover types and mortality classes (Ciesla, 1984). The spruce-fir slope type (greater than 50 percent crown cover in spruce-fir) with heavy tree mortality (greater than 30 percent of standing spruce-fir dead) was chosen to survey for eastern dwarf mistletoe. In western Maine, recent aerial photography was not available and sketchmapping was used to select the survey areas. The delineated areas (polygons) were ranked into three size classes: 100 acres, 100-500 acres, and greater than 500 acres. Polygons were randomly selected and examined within each region and size class.

A total of 39 polygons representing 35,504 acres were sampled: 15 in New Hampshire; 11 in Maine and New York; and two in Vermont. Within each selected polygon, clusters of three BAF 20 prism points were randomly located: Polygons smaller than 100 acres had two clusters; 100-500 acre polygons had three clusters; and polygons greater than 500 acres had four clusters and were divided into subunits based on drainage or ridge systems.

A total of 117 clusters were sampled: 45 in New Hampshire; 36 in Maine; 32 in New York; and 4 in Vermont. Of the 351 prism points examined, 136 were in New Hampshire, 108 in Maine, 95 in New York and 12 in Vermont.

Data Collection and Analysis

Site, stand, and individual tree data were recorded at each prism point. Site and stand information included elevation, aspect, slope, drainage, soil depth, crown closure, and stand age. For all "in" trees, data collected included species, dbh, crown position, and crown condition. In addition, spruce trees were rated for dwarf mistletoe intensity using Hawksworth's (1977) six class system. In this system, the tree's crown is divided into thirds. Each third is individually rated whether mistletoe infection is absent (score = 0), lightly infected (50 percent or less branches infected, score = 1), or heavily infected (more than 50 percent of branches infected, score = 2). The ratings for each third are added together to get the whole tree rating. The maximum rating (2 + 2 + 2 = 6) indicates a heavily infected spruce while a zero

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rating indicates an uninfected spruce tree.

This system was used to rate both live and dead spruce trees. We also noted dwarf mistletoe bole infections on live and dead trees. Altogether 841 spruce trees were examined on the prism points: 341 in New Hampshire; 247 in Maine; 238 in New York; and 15 in Vermont.

Results

The Adirondacks had 36.5 percent of the prism points with infected spruce trees (Table 1). New Hampshire had infected trees on 28.1 percent of its prism points compared to 18.2 percent in Vermont and 2.8 percent in Maine. Please note that only 15 spruce trees were rated in Vermont. Eastern dwarf mistletoe's incidence was greatest in New Hampshire where 88 percent of the infected area (24.7 percent of 28.1 percent) had more than 20 infected spruce trees per acre (Table 1). In the Adirondacks, 85 percent of the infected area had more than 20 infected trees per acre. In contrast, both Maine and Vermont had 88 percent of the infected area with less than 10 infected trees per acre.

Table 1--Proportion of heavy mortality area infected with eastern dwarf mistletoe by infection class

	Infection Class			
Region	1-10	11-20	21 +	Total
	Number of Infected Trees/Acre			
NY	4.4	1.0	31.1	36.5
NH	3.2	0.2	24.7	28.1
ME	2.3	0.2	0.3	2.8
VT	15.0	0.0	3.2	18.2

Eastern dwarf mistletoe incidence was greater on live compared to dead trees in Vermont, New Hampshire and Maine (Figure 1). The Adirondacks were an exception where mistletoe infections were more common on dead trees. The mistletoe intensity ratings ranged from 1-4 for infected trees in the Adirondacks, Maine, and Vermont. In contrast, New Hampshire had nearly equal percentages in each of the six mistletoe intensity rating classes (Figure 1).

Bole infections were present in each state mostly on live trees. However, Adirondacks bole infections were twice as common on dead trees compared to live trees.

Discussion

Dwarf mistletoe can cause growth losses, decline in tree vigor, degrade and tree mortality. Observations by Hawksworth in the past and during this survey indicate that eastern dwarf mistletoe should have similar impacts on red spruce. However, no data exists to quantify the relationship between mistletoe intensity levels and red spruce impacts in the northeast.

In our survey, eastern dwarf mistletoe was common in the Adirondacks, Vermont and New Hampshire but infrequent in western Maine. Eastern dwarf mistletoe appears to have its greatest impact in New Hampshire and New York where the highest mistletoe intensity ratings were documented. However, the data indicates that although eastern dwarf mistletoe is a contributing factor in red spruce's decline in the northeast, it does not appear to be a significant mortality agent. Most dead spruce did not have mistletoe brooms, even in the Adirondacks and New Hampshire where infection rates were highest. Also, most infected trees had low to moderate mistletoe intensity ratings (1-4) except in New Hampshire (Figure 1). Furthermore, the low to moderate mistletoe intensity ratings did not differ between live and dead spruce trees.

However, eastern dwarf mistletoe may be a more significant mortality agent than our survey indicates for two reasons. First, the mistletoe intensity rating system was designed to use branch infections. However, because mistletoe is small and cannot be seen with binoculars, the absence or presence of mistletoe brooms was used to rate trees. The branch infection pattern may be different than the brooming pattern on red spruce. Second, eastern dwarf mistletoe may actually kill trees that express only low to moderate intensity ratings based on brooms.

In conclusion, this survey indicates that eastern dwarf mistletoe is associated with heavy mortality areas in the Adirondacks, New Hampshire and Vermont. Eastern dwarf mistletoe appears to be a contributing factor in red spruce decline although it doesn't seem to be a significant mortality agent. Further work is needed to identify: 1) other factors associated with spruce-fir decline and mortality; 2) eastern dwarf mistletoe's relationship to other mortality agents of red spruce; and 3) better sampling methods to determine eastern dwarf mistletoe impact on red spruce.

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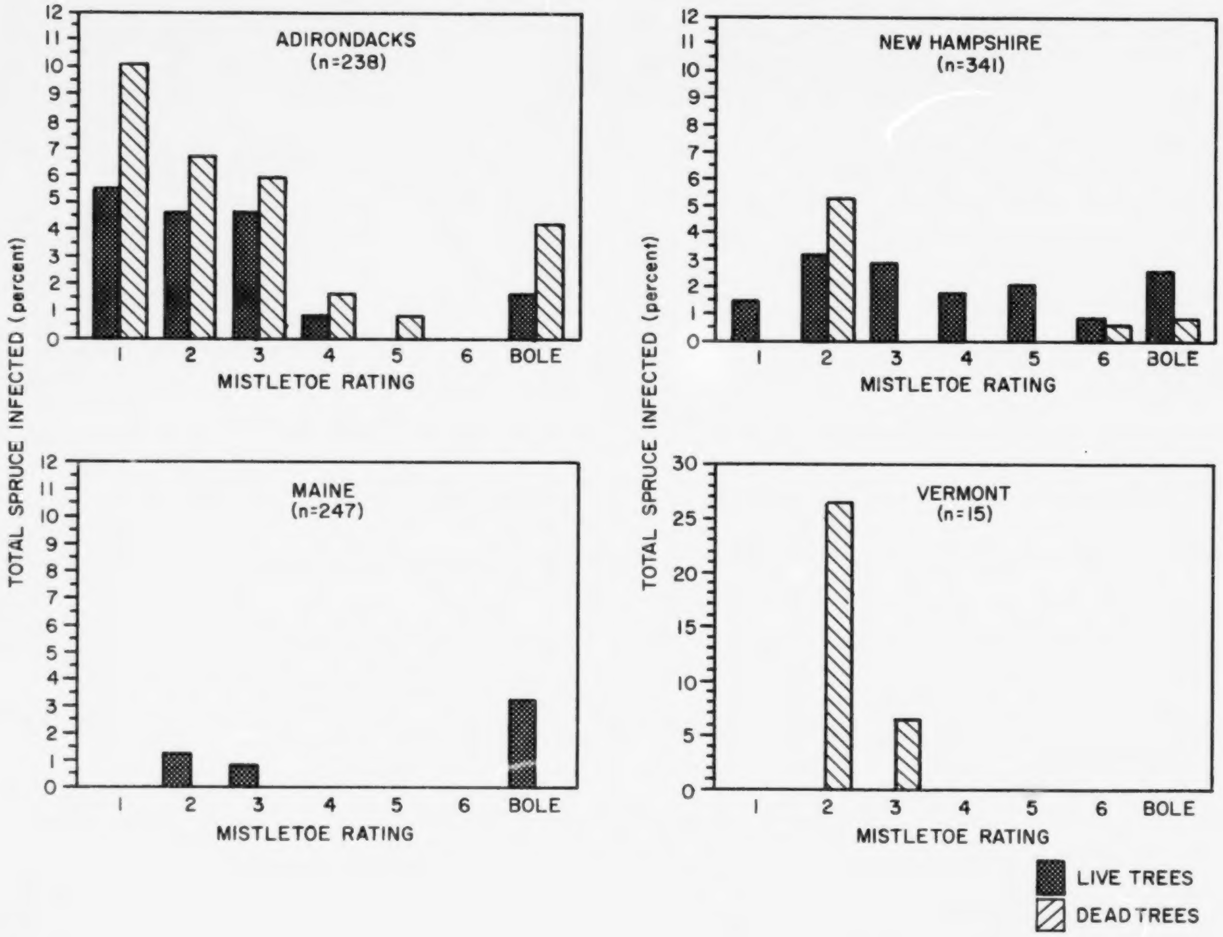

Figure 1.--Eastern dwarf mistletoe intensity ratings for each state surveyed in 1986.

The Conifer Swift Moth and Spruce-fir Decline

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Northern high-elevation spruce stands in Vermont have shown considerable dieback over the past two decades (Siccama et al. 1982; Vogelmann et al. 1985) yet the cause(s) of this spruce mortality is not known. While acid deposition is believed responsible, Johnson and Siccama (1983) conclude that the evidence does not show a clear cause and effect relationship between acid deposition and forest decline. More likely dieback is the result of many factors interacting to increase tree stress and eventually cause tree mortality.

In 1981, a large population of soil-inhabiting lepidopteran larvae were observed at elevations between 750 and 1100 m on Camels Hump Mountain in Huntington Vt. Densities were as high as 10/m^2 and were believed to be feeding upon spruce roots (Arthur Johnson, personal communication). In 1983, at an elevation of 915 meters on Camels Hump where spruce decline is most evident, we found a similar infestation of soil-inhabiting larvae which was identified as the Conifer Swift Moth, *Hepialus gracilis* Grote. Our 1985 studies turned up as many larvae as 100/m^2.

The Hepialidae, commonly referred to as the ghost or swift moths, are primitive lepidopterans that have attained their highest evolutionary development in the Australian region (Tindale 1938). The larvae are usually phytophagous, feeding on pasture grasses (Tindale 1933; Common 1970), or as stem borers of living trees (Tindale 1953). Although not well documented, some are suspected to feed on tree roots (Tindale 1932, 1935, 1964).

Although hepialids may be serious pests elsewhere, there is little information on the biology and behavior of the Hepialidae in North America (Engelhardt 1920; Prentice 1965; Kile et al. 1979; Wagner 1987). *Sthenopis argenteomaculatus* Harris, however, was reported breeding in red maple and alder swamps in New York (Leonard 1926) and has also been recorded as a borer in chestnut *(Castanea* sp.), oak *(Quercus* sp.), maple (*Acer* sp.), willow *(Salix* sp.), poplar *(Populus* sp.), and alder *(Alnus* sp.) (Felt 1906). *Sthenopis quadriguttatus* Grote bores in the roots of aspen *(Populus tremuloides)*, cottonwood *(Populus deltoides)*, and willow, (Furniss and Carolin 1977, Gross and Syme 1981). Another hepialid, *Hapialus mustelina* Pack., has been cited as a borer in spruce *(Picea* sp.) (Felt 1906: Packard 1895).

Our research objectives were (1), to develop survey procedures to monitor *H. gracilis* populations and determine their elevational and geographical densities and (2), to determine its life cycle and feeding habits. Different methods for measuring populations of hepialid larvae and adults were evaluated. The best method to assess larval numbers was random placement of ¼ m^2 soil excavations immediately adjacent to red spruce or balsam fir trees. The soil was removed down to the bedrock or inorganic soil horizon and total numbers of larvae recorded. After testing several different types of traps, trap colors, and trap heights for collection of adults, we found the most effective to be a ¼ m^2 sheet of clear plexiglass suspended 15 cm above the ground. Both sides of the trap were coated with an even layer (2 mm) of "Tangle-Trap".[1] This effectively captured moths flying into the trap enabling us to collect, count, and remove moths from the traps on a daily basis. Malaise traps also worked very well for the collection of adults but because of their expense and bulk, were used on a limited basis.

In 1984 on Camels Hump Mountain, five plots were established along the Burrows trail at elevations of 900, 950, 1006, 1050, and 1100 m. In early June, five ¼ m^2 soil excavations were dug in each plot and numbers of *H. gracilis* larvae and pupae recorded (Table 1). Additionally, eight ¼ m^2 sticky board traps were set up in a 12 meter diameter circle around plot center at each elevation. Traps were checked daily and all hepialid moths removed and counted thus providing us with a estimate of adult densities by elevation (Table 1). *H. gracilis* larvae, pupae, and adults were found at all five elevations but with fewer at the lowest and highest plots. This suggests that habitat and food preferences are important determinants of density; the plot at 900 m was in the transitional zone with a large hardwood component and the plot at 1100 m was pure balsam fir. Highest densities of all *H. gracilis* life stages were found where the predominant cover type was spruce-fir where forest decline is most evident and acidic deposition is purported to be highest.

In 1985 and 1986 adult trapping was continued in the five Burrows Trail plots and expanded to include a transect running from 700 m to 1150 m on the western slope of Camels Hump. Sixteen plots, placed every 30 m of elevation on the transect, each contained two ¼ m^2 clear sticky board traps. Four of these traps were also placed in each of the five Burrows Trail plots. Traps were set out in mid June and monitored daily through mid August. *H. gracilis* adults were counted and removed daily and any unusual specimens returned to the laboratory for identification.

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[1] The Tanglefoot Co., 314 Straight Ave., S.W., Grand Rapids, Michigan 49504

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Table 1.--Total number of *H. gracilis* pupae and larvae; Camels Hump Burrows Trail plots

Plot	Elevation (meters)	1984 Pupae	1984 Adults	1985 Adults	1986 Adults
1	884	1	63	0	14
2	945	9	216	2	191
3	1006	15	181	2	207
4	1067	19	275	0	242
5	1128	4	66	0	179

Total *H. gracilis* adult catches in 1985 were 4 individuals in the Burrows Trail plots and 5 individuals in the transect plots. Adult catches in 1986 were 833 individuals in the Burrows Trail plots and 753 individuals in the transect plots. The 1984 and 1986 adult catches and 1985-1986 larval sampling indicates that *H. gracilis* has a two-year life cycle on Camels Hump. In 1986 the highest trap cacthes were in the spruce-fir zone between the elevations of 950 m and 1100 m (Table 1). *H. gracilis* adults were caught at every plot along the transect line but in very low numbers below the spruce-fir/hardwoods transition zone.

Peak adult emergence in 1984 and 1986 was during mid-July. The period of adult activity extended from the last week of June through the first week of August; adults were most numerous between July 7 and July 21. We found *H. gracilis* to have two daily flights; one at dusk and the other at dawn. The dusk flights occurred from sunset to roughly one-half hour past. These flights appeared to be dispersal and/or mating flights although we observed no coupling at this time. Flight behavior was fast and erratic at heights up at 3 m. Towards the end of the dusk flights females could be seen flying slower than the males while broadcasting eggs singly onto the ground. The dawn flights are short, taking place during the 30 minutes preceeding sunrise. This flight consisted mainly of slow-flying, egg laying females broadcasting eggs in a apparently non-discriminating fashion.

H. gracilis adult and larval activity was also found in 19 out of 20 other permanent plots throughout Vermont within the Green Mountain National Forest (Table 2). Five ¼ m² soil excavations were dug and two sticky board traps were monitored at each of these sites. Numbers of *H. gracilis* were found to be positively correlated with site elevation with more individuals at the highest elevations. The plot sites ranged in elevation from 198 m to 1128 m. The only plot lacking *H. gracilis* was the one at 305 m.

Larvae were observed in the field and collected weekly from the time they eclosed in late 1984 through to pupation in June 1986. Observations of feeding habits indicate that they are polyphagous and that the bulk of the population migrates from one food source to another as the larvae mature. Young larvae are often found feeding in moss spp. that cover much of the ground at these elevations. The young larvae are also found closely associated with and feeding on the petiole bases of the mountain wood fern *(Dryopteris campyloptera)* and the fine roots of balsam fir *(Abies balsamea)* and red spruce *(Picea rubens)*. In a laboratory study, young to mid instar larvae fed extensively on and in some cases completely consumed the root systems of seedlings of balsam fir *(Abies balsamea)*, red spruce *(Picea rubens)*, white spruce *(Picea glauca)*, mountain ash *(Sorbus americana)*, and white birch *(Betula papyrifera* var. *cordifolia)* (Table 3). In mid summer 1985 on Camels Hump between the elevations of 950 m and 1100 m, we found a large number of dead seedlings which when examined, showed root girdling and damage similar to the seedling injury we observed in our controlled feeding studies in the laboratory.

As the larvae mature they move to the larger roots (1st, 2nd, and 3rd order) of balsam fir and red spruce. They do not bore within the roots but cause extensive damage to inner bark, phloem, and exterior xylem. Entire roots may be girdled. One large balsam fir had 32 major wounds on the 1rst and 2nd order roots out to 50 cm. We have observed similar extensive root damage to red spruce both on Camels Hump and Mount Abraham in Lincoln Vermont. Late instar *H. gracilis* larvae are seldom found tunneling in the roots; a trait common with many other Hepialids. However, we did observe them tunneling in the petiole bases of the mountain wood fern.

The root feeding by *H. gracilis* is considered a contributing factor to the decline of high elevation balsam fir and red spruce. We have determined that *H. gracilis* is an abundant component of high elevation conifer stands, particularly those in the process of decline. Tests have proven that even a single larva is capable of killing a seedling. This could be an impact upon stand regeneration. The feeding of the full grown larvae on the root systems of apparently healthy spruce and fir trees produces injury which could serve as infection courts for various wood decay fungi such as *Armillaria mellea* and *Verticicladiella* sp. There is the indication that the presence of *H. gracilis* is an indicator of spruce-fir decline and may indeed be a useful component for assessing acidic deposition levels.

Acknowledgments

Diantha Howard was a great help with the statistics. Dave Wagner was very helpful throughout the study and with the editing of this manuscript. This work was supported in part by a grant from the United States Forest Service and Coal Producers (Consol., AMAK, Peabody).

Table 2.--Total number of *H. gracilis* larvae and adults in 20 Green Mountain National Forest plots by elevation

Plot #	Location	Elevation (meters)	# larvae (5 pits)	# adults (2 traps)
20	Bristol Vt.	198	0	14
1	Rochester Vt.	305	0	0
18	Hancock Vt.	381	2	10
6	Ripton Vt.	396	1	4
11	Granville Vt.	396	0	24
9	Ripton Vt.	442	4	5
10	Granville Vt.	458	1	7
15	Hancock Vt.	473	1	10
2	Granville Vt.	518	21	1
5	Ripton Vt.	534	4	8
4	Granville Vt.	549	11	15
19	Hancock Vt.	549	2	3
3	Granville Vt.	671	6	17
7	Middlebury Gap	717	8	41
8	Lincoln Vt.	824	9	38
17	Mt. Mansfield	884	16	46
16	Mt. Abraham	946	3	43
14	Mt. Mansfield	1006	33	34
13	Camels Hump	1068	35	59
12	Camels Hump	1128	41	43

Table 3.--Laboratory feeding study with *Hepialus gracilis* larvae using tree seedlings and fern petiole bases.

Species	Treatment: number of larvae	Root Length in cm Petiole base volume in ml		
		Mean before	Mean after	p*
Balsam fir	0	489.5	475.5	a
Balsam fir	1	564.6	343.7	a
Balsam fir	5	549.3	13.9	b
Red spruce	0	148.2	304.4	a
Red spruce	1	200.5	32.7	b
Red spruce	5	177.6	7.5	b
White spruce	0	318.0	391.3	a
White spruce	1	270.9	150.8	b
White spruce	5	351.0	20.4	b
Mountain ash	0	88.3	86.3	a
Mountain ash	1	95.5	25.5	b
Mountain ash	5	94.3	22.5	b
White birch	0	75.6	104.0	a
White birch	1	78.0	12.4	a
White birch	5	87.7	0.2	b
Dryopteris	0	8.2	8.6	a
campyloptera	1	8.3	7.2	b
fern	5	8.4	6.1	b

p* = signifigant difference in "after" measurements between treatments; adjusted for "before" measurements by analysis of covariance. Means followed by the same letter are not significantly different at p = 0.05.

Effects of Ozone on the Physiology of Red Spruce Seedlings

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Introduction

Red spruce die-back in both Germany and North America has been proposed to be caused by the interaction of multiple stresses (Johnson and Siccama 1983, 1984, Friedland et al. 1984, Blank 1985, Rehfuess 1987). Data accumulated over more than a decade from conifers growing around industrial areas in Finland indicate that those trees are more susceptible to winter injury in comparison to trees from relatively unpolluted environments (Havas 1971, Huttunen 1978, Huttunen et al. 1981). This pattern suggests that industrial pollutants are in some way altering frost resistance of trees. Frost injury of affected trees has repeatedly been reported in the case of the German forests where ozone has explicitly been proposed to play a central role in the decline phenomenon (Rehfuess 1987). The results of Brown et al. (1987) suggest that ozone levels which produced no visible symptoms during the season of active growth may reduce subsequent frost resistance of previously exposed Norway spruce seedlings.

Ozone is known to affect growth and yield of many crop plants and to bring about premature senescence in some cases (Kohut et al. 1986). The physiological basis for this change is not fully understood, but it is thought to be mediated through both an inhibition of photosynthesis (Reich and Amundson 1985) and an impairment of assimilate translocation from source leaves (McCool and Menge 1983). Since ozone can give rise to free radicals in solution (Heath 1987) and to the highly toxic hydroxyl radical in vivo (Grimes et al. 1983) its adverse effects on growth and yield may be partially an expression of lipid peroxidation, loss of subcellular compartmentation, and enzyme inactivation (Alscher et al. 1987ab)

An alternative approach is taken by Davison and Barnes (1987) who suggest that air pollutants may act to impair the physiological activities which underlie seasonal rhythms of active growth, hardening, and dormancy. In the case of conifers, an effect on hardening could be expressed as alterations in such processes as starch mobilization and its conversion to sugars, the production of tannins, increases in antioxidant levels, changes in chloroplast ultrastructure or the cessation of photosynthesis, all of which occur as the tree becomes dormant (Esterbauer and Grill 1978, Aronsson et al. 1976, Soikkeli 1978, Senser and Beck 1984, Huttunen and Soikkel 1984).

The extent of photooxidation of chlorophyll which occurs at low temperatures in unstressed conifers may be increased under conditions where free radicals are being generated through the action of an air pollutant such as ozone (Davison and Barnes 1987, Mehlhorn et al. 1986, Elstner et al. 1985). This may be due to the exhaustion of the antioxidant mechanisms of the plant cell. An analogons mechanism for crop plants has already been proposed (Alscher and Amthor 1987, Alscher et al. 1987ab).

It follows from this discussion that four distinct effects of ozone on conifers are possible:

1. effects on assimilate production, utilization, and seedling growth.
2. alterations in the timing of phenological events.
3. interactions between ozone and low temperature stresses producing high levels of free radicals.
4. exhaustion of antioxidant reserves.

The goal of our research program is to assess the effects of ozone on red spruce physiology and growth. Measurement of responses throughout the winter hardening period may allow us to distinguish among the above possibilities.

Materials and Methods

Plant Material

1986. Three-year-old nursery-grown seedlings (from a 1958 Vermont provenance seed collection from the Warren-Randolf, VT area) were lifted in the fall of 1985. Bare-rooted seedlings were potted in 1:1 peat:vermiculite in January and stored in a unheated greenhouse until April when bud expansion commenced. Seedlings were moved to the field research site and were shaded beneath snow fencing. Following bud break and flush expansion, a population of seedlings were selected which did not exhibit water stress symptoms and which were fairly uniform in size. Seedlings were watered as necessary with tap water. Ozone fumigations commenced in late June after flush elongation had ceased.

1987. Two-year-old greenhouse-grown seedlings (from a 1985 South Range, Nova Scotia provenance collection) were grown in 1:1:1 peat:vermiculite:sand. Seedling dormancy was induced under cold greenhouse conditions. Seedlings were transferred to the field in May and fumigations commenced on June 1, immediately after bud break.

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Ozone Fumigations

1986. Three O_3 levels were delivered in open-top chambers. All chambers received charcoal filtered air to which ozone was added to levels representing charcoal filtered, ambient, and two times ambient (designated as cf, 1x, and 2x) for 12 h d^{-1}, 7 d wk^{-1}, 16 wks. Fumigations were delivered as multiples of ambient by the use of a proportional controller. Fumigation patterns were characteristic of a rural site (Ithaca, NY).

Each treatment was represented by 2 chambers (replicates). At approximately monthly intervals, 3 seedlings from each chamber were assessed for various physiological and biochemical responses to ozone. Data were analyzed in a 3 x 4 (ozone by harvest date) factorial arrangement. Appropriate single degree of freedom contrasts were made to compare main and treatment effects as well as interactions.

1987. Seedlings were exposed to 5 levels of ozone in an analogous manner as above. Only cf treatments received charcoal filtered air. Other treatments were 1x, 2x, 3x, and 4x ambient. In addition, non-chambered, ambient plots were used. The daily length of the fumigations followed changes in day length; fumigations commenced 2 h after sunrise and were terminated 2 h before sunset.

Each treatment was represented by 3 replicate chambers. At biweekly intervals, one seedling from each chamber were transported to a controlled environment chamber. Photoperiod (550 uE m^{-2} s^{-1} from mixed HPS and mixed metal halide lamps) and temperature regimes in the chamber were adjusted to reflect Ithaca, NY conditions for each date of the harvest. Temperature regimes were calculated from 5 year meteorological data collected for Ithaca (Department of Meteorology, Cornell University, Ithaca, NY). Following overnight acclimation, seedlings were harvested 4 hr after the start of the light period. Various physiological and biochemical measurements were made as outlined below. Data are treated as a 4 x 12 (ozone by harvest date) factorial design.

Physiological Measurements

Carbohydrate analysis. Dried, ground plant material was assayed for total soluble sugars (anthrone reaction) and starch (enzymatic hydrolysis) according to the methods of Ebell (1969) and Ou-Lee and Setter (1985).

Photosynthetic gas exchange. Photosynthetic CO_2 uptake was measured using a LiCor 6000 photosynthesis meter with a 250 mL cuvette.

Pigment levels. Chlorophyll a and b and carotenoids were measured in acetone extracts of needle material according to Weilburn and Lichtenthaler (1984).

Photosynthetic electron transport. Chloroplasts are obtained from the needles of red spruce by a modification of the method of Senser and Beck (1978). Following the isolation procedure, the chloroplasts are resuspended at a concentration of ca. 300 μg ml^{-1} chlorophyll. Measurement of coupled and uncoupled photosynthetic electron transport are monitored in a Clark oxygen electrode either as light-driven oxygen uptake in the presence of methyl viologen (100 μm final concentration) as an electron acceptor or as oxygen evolution using ferricyanide (1.3 mM final concentration) as acceptor.

Light Microscopy. Needles are fixed in buffered glutaraldehyde or a mixture of glutaraldehyde and (para)formaldehyde. Tissues are then postfixed in buffered osmium tetroxide, dehydrated in ethanol, and embedded in low viscosity resin. Sections for light microscopy are stained with toluidine blue. Thin sections for transmission electron microscopy are stained with uranyl acetate followed by lead citrate.

Results and Discussion

The results presented here are those obtained during the first and part of a second year of a multi-year study to investigate the effects of ozone on the physiology of red spruce seedlings, growth, and development. A wide array of growth and physiological parameters is being measured in an effort to correlate possible changes in growth with seasonal changes in seedling physiology. A majority of the physiological parameters reported here relate to carbon fixation, partitioning, and utilization.

Red spruce seedlings exposed to ozone during the summer and fall of 1986 exhibited changes in gas exchange rates, photosynthetic electron transport, and foliar pigment levels (Table 1). Ozone treatment interacted with duration of exposure in some cases, the relative difference between control (charcoal filtered) seedling response and ozone exposed seedling reponse being greatest at the final harvest which occurred in mid-October (Table 2). No differences between charcoal-filtered and exposed samples was detected during the summer months. Photosynthesis is known to decrease during the hardening-off period in unstressed conifers as the plants become dormant (Oquist 1983) and so this ozone-mediated alteration of the normal pattern of photosynthetic activity is potentially of great significance.

Interestingly, changes in photosynthesis (on a gdw basis) and electron transport were not reflective of changes in chlorophyll content (Figure 1), and photosynthesis stated on a chlorophyll basis indicates that photosynthetic activity of the remaining pigment is enhanced by ozone treatment. A detectable decrease in carotenoid content in ozone-exposed needles was measured in the samples taken in October (Figure 2).

Red spruce seedlings exposed to ozone exhibited decreased levels of photosynthetic pigments, perhaps as a consequence of oxidative action on the thylakoid membranes. This is in agreement with reported effects of ozone on pigments in the leaves of crop plants (Elstner et al. 1985). Our data suggest, however, that in the case of red spruce, this oxidative effect is potentiated by specific conditions of photoperiod and temperature, as the effect was detected after the normal period of dormancy induction. Winter

Table 1.--Effects of ozone on various physiological variates in red spruce seedlings[a]

Variate	Treatment		
	cf	1X	2X
Photosynthesis[b]	2.34 ± 0.25x	2.69 ± 0.09xy	2.82 ± 0.17y
Respiration[c]	1.20 ± 0.16	1.29 ± 0.16	1.42 ± 0.15
Electron transpart[d]	49.6 ± 3.6	54.7 ± 3.7	56.0 ± 3.8
Total chlorophyll[e]	1797 ± 102x	1599 ± 77y	1585 ± 89y
Carotenoids[f]	361 ± 19x	336 ± 13xy	328 ± 17y

[a] Means and standard errors represent main treatment effects of ozone treatment calculated from 8 observations, 2 chambers for each of 4 harvests. Values within rows followed by different letters are statistically different at $P < 0.05$. cf - charcoal filtered, lx - ambient, 2x - two times ambient.

[b] ug CO_2 mg chl^{-1} h^{-1}.

[c] mg CO_2 mg dr wt^{-1} h^{-1}.

[d] umol O_2 mg fr wt^{-1} h^{-1}.

[e] mg chlorophyll g fr wt^{-1}.

[f] mg carotenoid g fr wt^{-1}.

Table 2.--Effect of ozone at two harvest times on some physiological responses in red spruce seedlings[1]

Variate	Harvest			
	July		October	
	cf	Ozone	cf	Ozone
Photosynthesis	2.74a	2.53a	1.50b	2.52a
Chlorophyll	1733a	1921b	2135c	1525d
Carotenoids	353a	371a	404b	299c

[1] Units and analyses as in table 1.

hardening itself is also potentiated by specific conditions of photoperiod and temperature (Aronsson et al. 1976). It is possible, therefore, that ozone affected the hardening process itself during our 1986 study. Alternatively, the antioxidant systems of the mesophyll cells may have become exhausted by the joint stress of ozone and lower temperatures which occurred in the fall. The oxidation of pigments was accompanied, however, by a compensation mechanism which resulted in greater photosynthetic activity in the remaining functional photosynthetic apparatus. The nature of this putative mechanism is not known and the underlying physiological mechanism which brings about dormancy in unstressed seedlings may have been affected by ozone exposure.

The winter hardening process includes breakdown of accumulated starch which is mobilized to form raffinose and other soluble sugars (Little 1970, Senser et al. 1971, 1975). Our data indicate that exposure to ozone resulted in a shift in the time course for starch mobilization in the late summer (August) of 1986 (Figure 3A). An affect of ozone exposure on an early peak of starch which occurred in the second year experiment (June 1987) was also detected (Figure 3B). The 1986 data are in agreement with those of McCool and Menge (1983) who demonstrated an ozone-mediated inhibition of assimilate translocation in leaves of tomato plants.

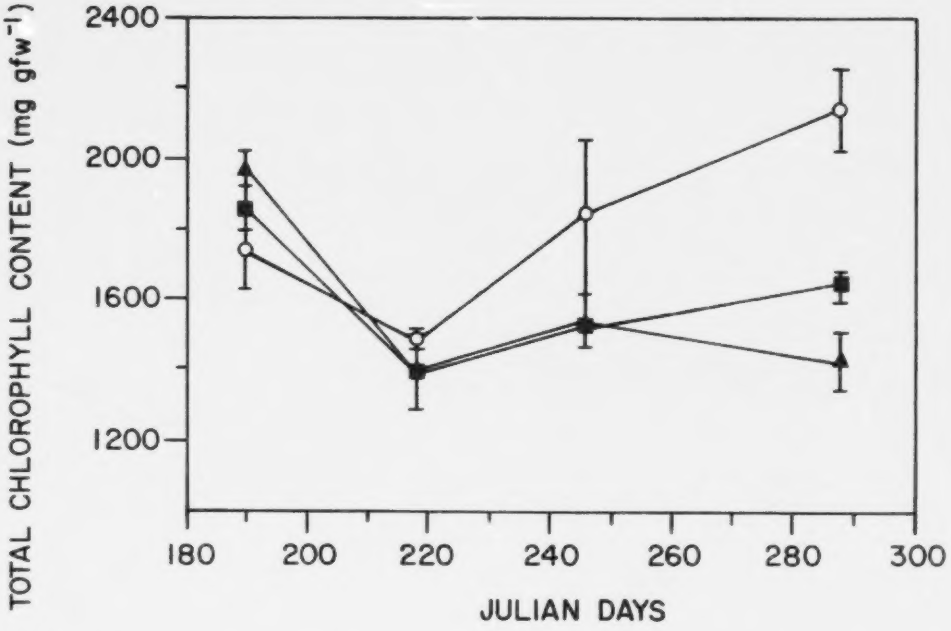

Figure 1.--Effect of ozone exposure on total chlorophyll content of new needles of red spruce seedlings, June - October, 1986; seedlings exposed to (O) charcoal-filtered air, (■) 1 x ambient ozone, and (▲) 2 x ambient ozone.

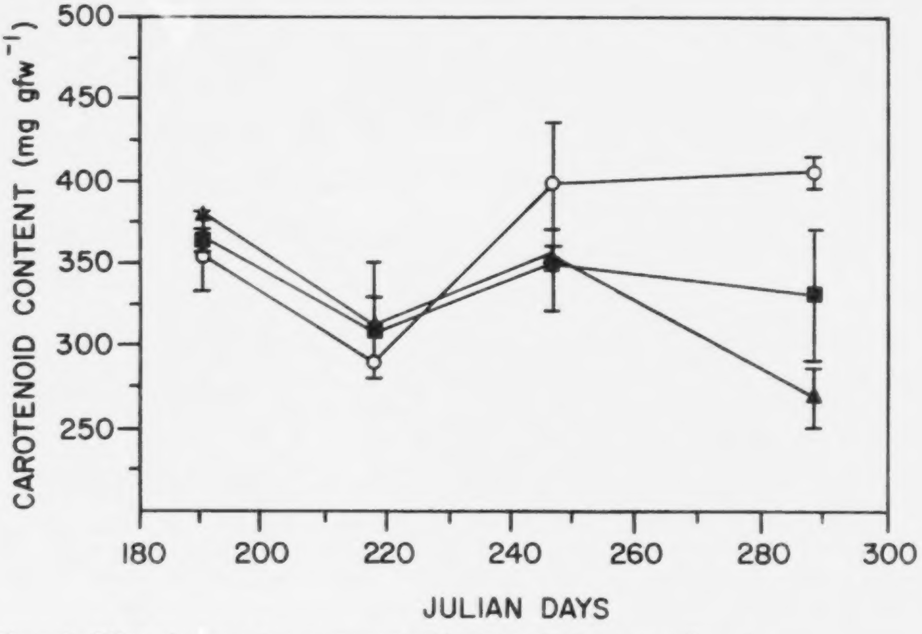

Figure 2.--Effect of ozone exposure on carotenoid content of red spruce seedlings, June - October, 1986; seedlings exposed to (O) charcoal-filtered air, (■) 1 x ambient ozone, and (▲) 2 x ambient ozone.

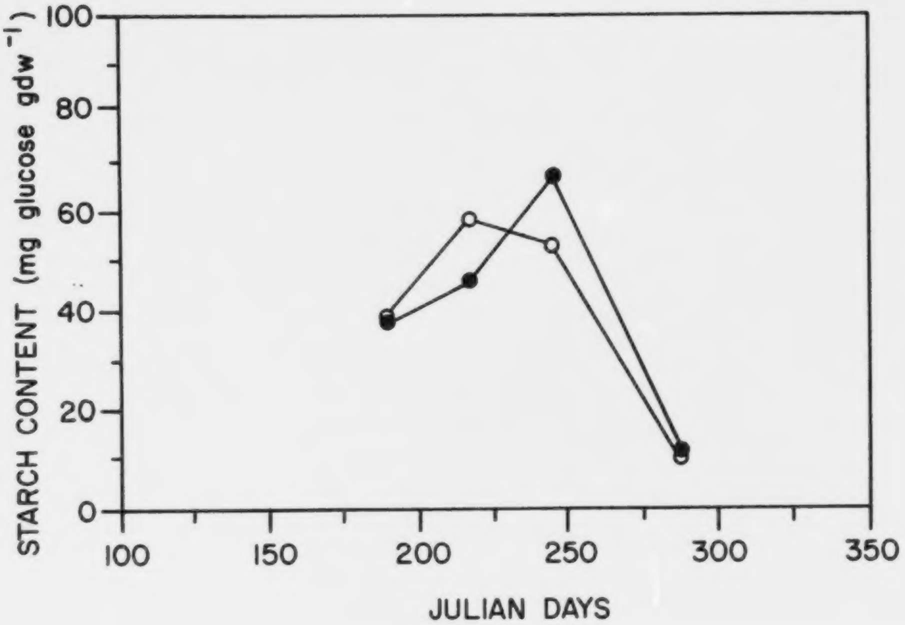

Figure 3a.--Effect of ozone on starch levels in new needles of red spruce seedlings, 1986; seedlings exposed to (O) charcoal-filtered air and (●) ozone.

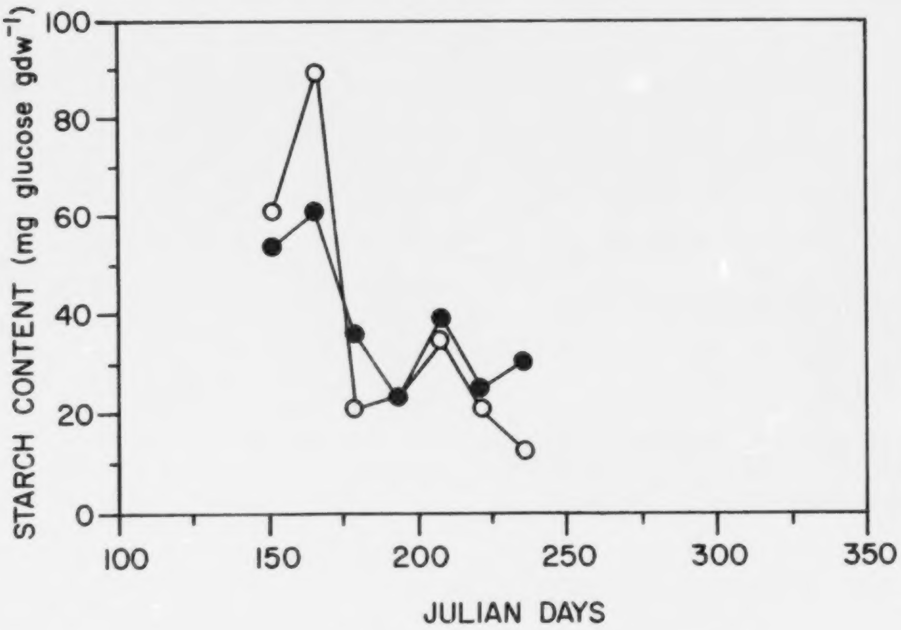

Figure 3b.--Effect of ozone on starch levels in new needles of red spruce seedlings, 1987; seedlings exposed to (O) charcoal-filtered air and (●) ozone.

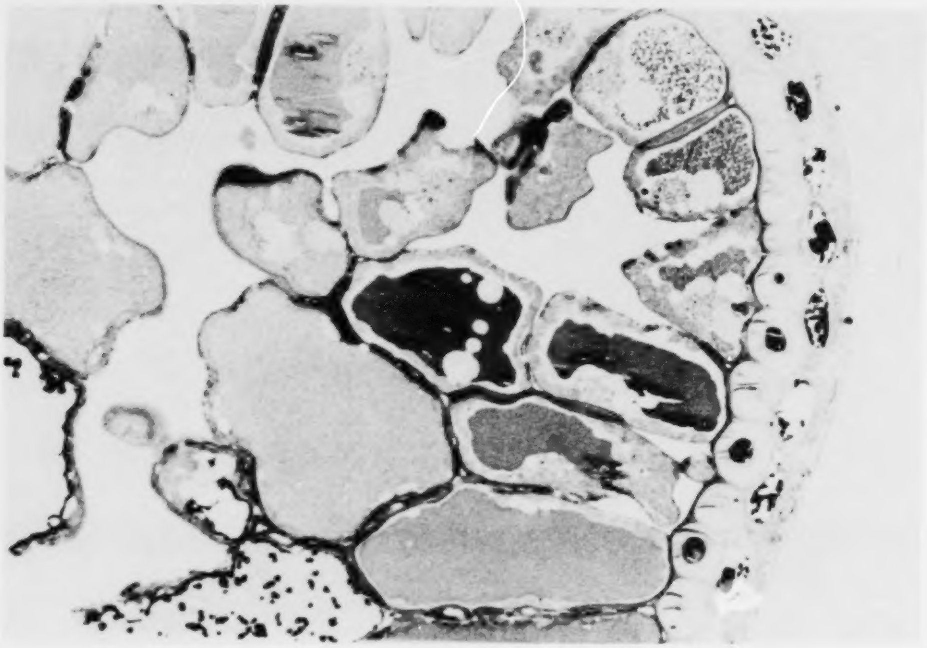

Figure 4.--Cross-section of red spruce needle exposed to charcoal-filtered air from June 17 - September 28, 1986; magnification - 500 x.

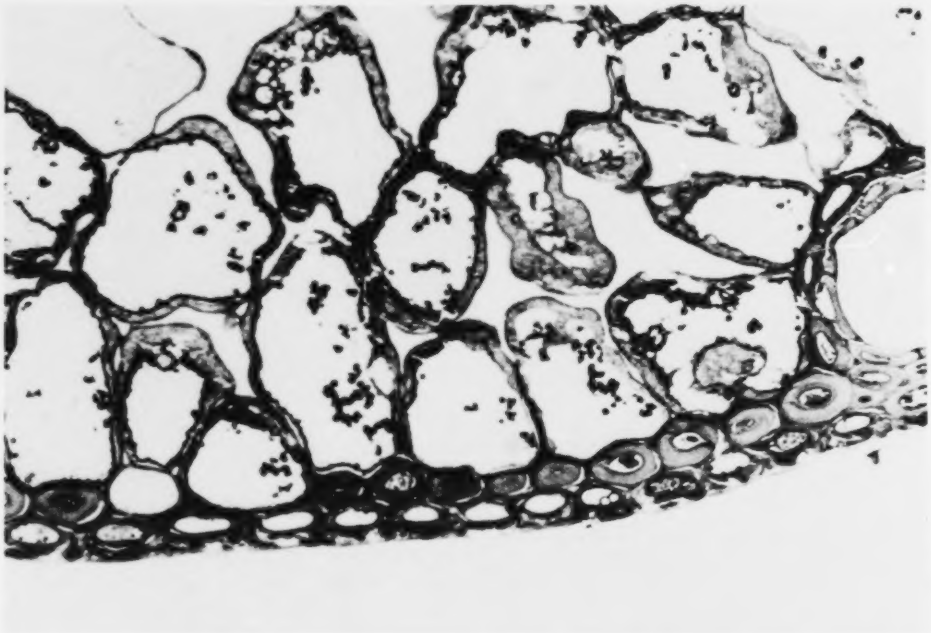

Figure 5.--Cross-section of red spruce needle exposed to 2 x ambient ozone from June 17 - September 28, 1986; magnification - 500 x.

Starch mobilization which occurs during the late summer in conifer seedlings exposed to ambient environmental conditions such as those occurring in Ithaca, NY is most probably associated with the winter hardening process (Soikkeli 1978). Ozone may have influenced this early phase of winter hardening so as to cause a delay in starch mobilization. Future work is necessary to establish whether ozone affects the winter hardening process itself or whether its effect on starch mobilization is unrelated to the potentiation of winter injury.

Ultrastructural examination of needle tissue showed evidence of the appearance of densely-staining material in the vacuoles of control mesophyll cells during September, 1986 (Figure 4). This accmulation is one normally associated with the hardening process. In contrast, this material did not appear to accumulate to the same extent in the vacuoles of ozone-exposed cells during the early fall (Figure 5). Additionally, one can note a precipitation of densely-staining material in cells of ozone-exposed needles. Again, it would seem that exposure to ozone leads to a delay in, or an alteration of, processes associated with the hardening-off process. As in the case of the observed changes in photosynthetic rates, the mechanism through which ozone affects the hardening process is as yet not understood.

Preliminary results for the summer months of 1987 indicate an effect of ozone on growth (Figure 6). There was no detectable effect of ozone on growth during the summer of 1986, but this may have been due to differences between bare-root and container-grown seedlings. The data of Figure 7 show ozone-mediated changes in the pattern of seedling growth including decreased old tissue mass, root mass and change in the proportions of determinate to indeterminate growth in 1987. These results are in agreement with that obtained in one-year old seedlings exposed to ozone in controlled environmental chambers (data not shown).

In conclusion, we have noted both biochemical and physiological effects of ozone exposure in spruce seedlings. It is of great interest to determine whether the primary effect of ozone on conifer physiology is one of growth retardation or whether a specific effect on winter hardening off is also involved. Changes in growth patterns and phenology may increase the susceptibility of foliage to winter injury, one of the reported observations in declining trees.

Acknowledgments

The authors wish to thank Paul van Leuken, Suzanne Fellows, Bill Bicknell and John L. Bower for expert technical assistance.

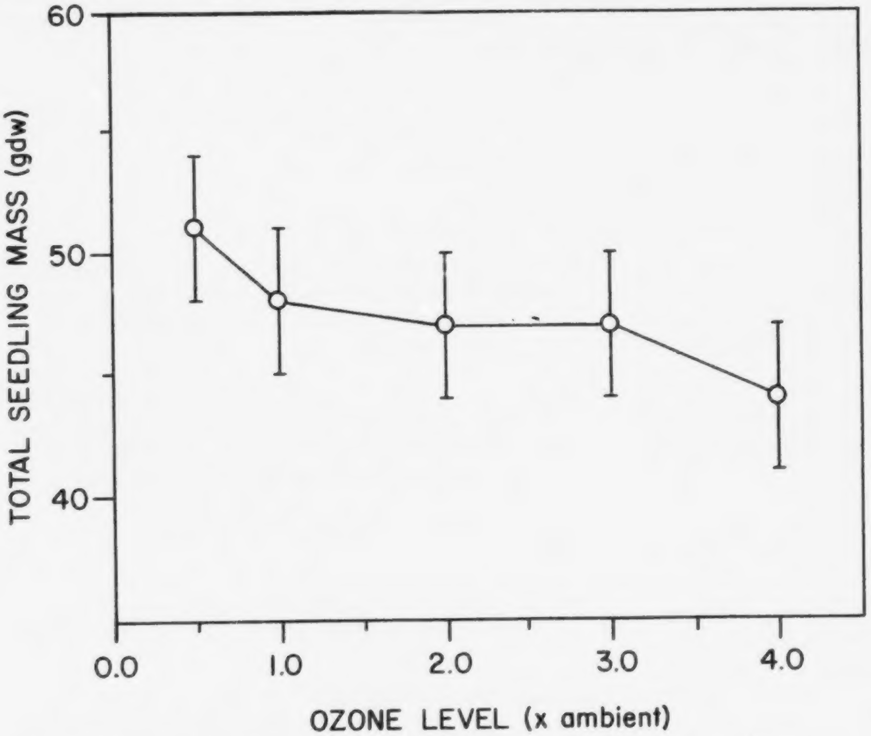

Figure 6.--Effect of ozone exposure on total biomass of red spruce seedlings, June - October, 1987.

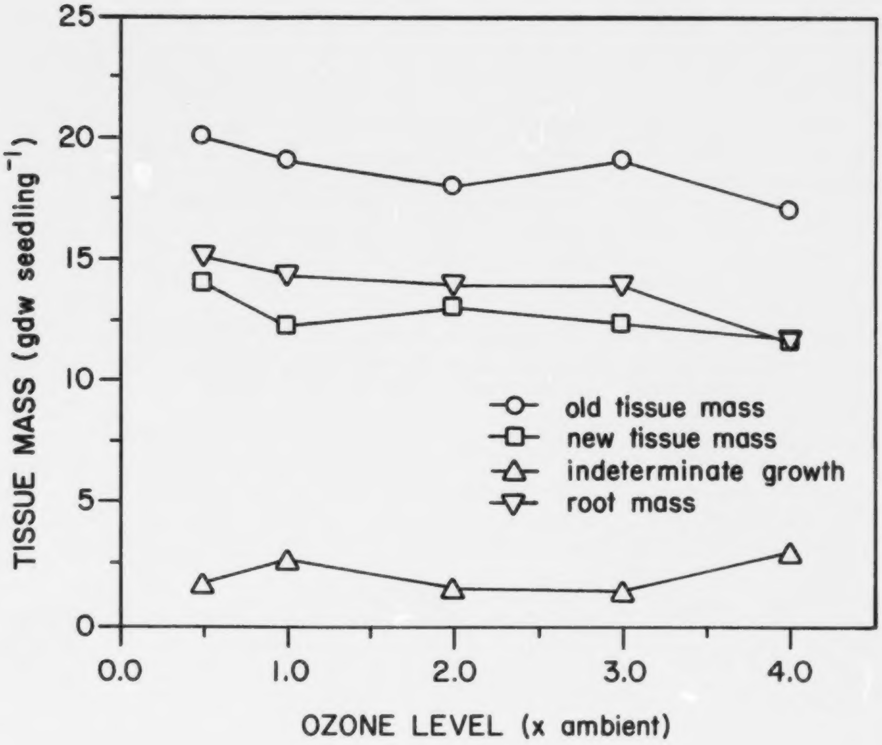

Figure 7.--Effect of ozone exposure on growth of red spruce seedlings, June - October, 1987.

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Isozymes of Superoxide Dismutase in Red Spruce and their Importance in Protecting against Oxidative Stress

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Introduction

Some of the air pollutants believed responsible for the decline of forests, particularly SO_2 and ozone, can generate toxic oxygen radicals when introduced into biological systems (Asada, 1980; Peleg, 1976). The primary defense against the oxygen compounds superoxide and hydrogen peroxide involves the enzymes superoxide dismutase (SOD), peroxidase and catalase. Each of these enzymes exists as a group of enzymes of identical activity but different composition called isozymes. Different isozymes of SOD in maize have been shown to respond differently to oxidative stress (Matters and Scandalios, 1986). Previously we reported that SOD in red spruce needles *(Picea rubens)* showed a large increase in activity when the needles hardened before their first winter (fig. 1). The mechanism of cold stress has been suggested to be similar to the mechanism of oxidative stress.

Hydrogen peroxide (H_2O_2) is also an irreversible inhibitor of two forms of SOD, the CuZn SOD and Fe SOD (Bridges and Salin, 1981). Since hydrogen peroxide is reported to occur as an air pollutant (Masuck *et al.,* 1986), it is possible that H_2O_2 could be acting synergistically with other pollutants by inhibiting the SOD activity and weakening the trees defense against sources of superoxide.

In this report, the electrophoretic separation of the isozymes of SOD from red spruce needles is presented. The responses of the isozymes to winter hardening and, in solution, to hydrogen peroxide are shown.

Materials and Methods

Plant Material

3/0 provenance seedling material was supplied by the USFS. Some bare-rooted seedlings were potted in Duke Research mix and grown in the Duke Greenhouse. Other bare-rooted seedlings were potted in 1:1 peat:vermiculite and were maintained in a dormant state in a cold greenhouse at the Boyce-Thompson Institute, Ithaca, NY. Seedlings were moved to the field prior to bud break in the spring, 1986. They were transferred to open-top chambers in early June.

Harvests

The seedlings at Duke, as needed, were moved to the Ecotoxicology Laboratory at Duke where the needles were clipped, homogenized and analyzed.

The needles from the Boyce-Thompson Institute were harvested at monthly intervals from July to October. The needles, as they were clipped, were placed in vials and immediately immersed in liquid nitrogen. The samples were shipped in liquid nitrogen to the Ecotoxicology Laboratory and stored at -70°C until analyzed.

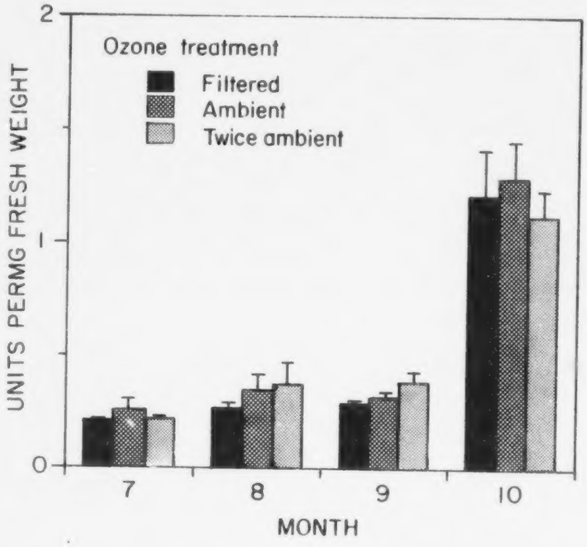

Figure 1.--Superoxide dismutase activity in ozone-exposed red spruce.

Analytical Procedures

The SOD activity was determined by the method of Beauchamp and Fridovich (1971) or McCord and Fridovich (1969). For the assay of McCord and Fridovich, the needles had to be homogenized in the presence of polyvinylpolypyrrolidone and the whole homogenate dialyzed. Polyacrylamide gel electrophoresis was performed as described by Beauchamp and Fridovich (1971), as was the photochemical staining with nitrobluetetrazolium and riboflavin. The gels were scanned at 560nm using a Shimadzu 260 spectrophotometer. Since the SOD activity appears as achromatic bands, the scans are inverted so the activity appears as peaks.

Results

The isozymes of SOD in red spruce are shown in the top trace of figure 2. Six bands were observed, five of which migrated as a group. The second trace in fig. 2 shows a gel that was soaked in KCN (an inhibitor of CuZn SOD) before staining. The third trace is a gel that was soaked in H_2O_2 before staining. This shows that there is no Fe SOD in red spruce and band 1 is Mn SOD. Bands 1 and 6 did not always appear. The reasons for band 6 being ephemeral were not apparent, but band 1 probably wasn't always seen because the enzyme was relatively unstable. When dialyzed extracts of the spruce needles were kept at 4°C for 2

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weeks, the Mn SOD activity was lost in 24 hrs., the rest of the activity remained unchanged after 2 weeks.

Figure 3 shows scans of gels of needles from filtered chambers assayed for figure 1. The top trace represents August needles which by the assay of McCord and Fridovich has 54 units/g wet weight. The second trace is October needles (185 units/g wet wt). The last trace represents one year old needles grown in the Duke greenhouse (705 units/g wet wt). The gels are indistinguishable except for band 6, the significance of which is questionable. As a control, new and one year old needles from a seedling in the Duke greenhouse were analyzed. The gels were identical even though the new growth had an activity of 110 U/g and the year old needles had an activity of 377 U/g.

Another pollutant, which is an inhibitor of SOD, is hydrogen peroxide. A dialyzed extract of spruce needles was incubated with 10 mH H_2O_2 and 1 mM KCN (to inhibit peroxidase). The KCN was later removed by dialysis. Aliquots that had been exposed to peroxide for 0.5, 1.0 and 1.5 hrs. were assayed for SOD activity (fig. 4) and electrophoresed (fig. 5). During the 1.5 hr. experiment, 58% of the SOD activity was lost. As shown in fig. 5 and fig. 6, all of the loss in activity occurred in 2 isozymes, with an almost total loss of isozyme 2. Fig. 6 is a very crude quantitation of the residual activity of each isozyme based on peak height.

Discussion

The result in fig. 3 indicates that the winter hardening of spruce needles does not induce different isozymes of SOD to different extents as does oxidative stress in maize. This does not necessarily conflict with the view that oxidative stress and cold stress follow similar mechanisms. Aside from the obvious differences in plants, there is the fact that the trees in the Duke greenhouse show a similar response even though the lowest temperature they ever received was 10°C. The needles also appear to show the same induction no matter when in the summer the bud opened. Thus it seems likely that the stimulus for the increase in SOD activity is the length of the day, not cold stress.

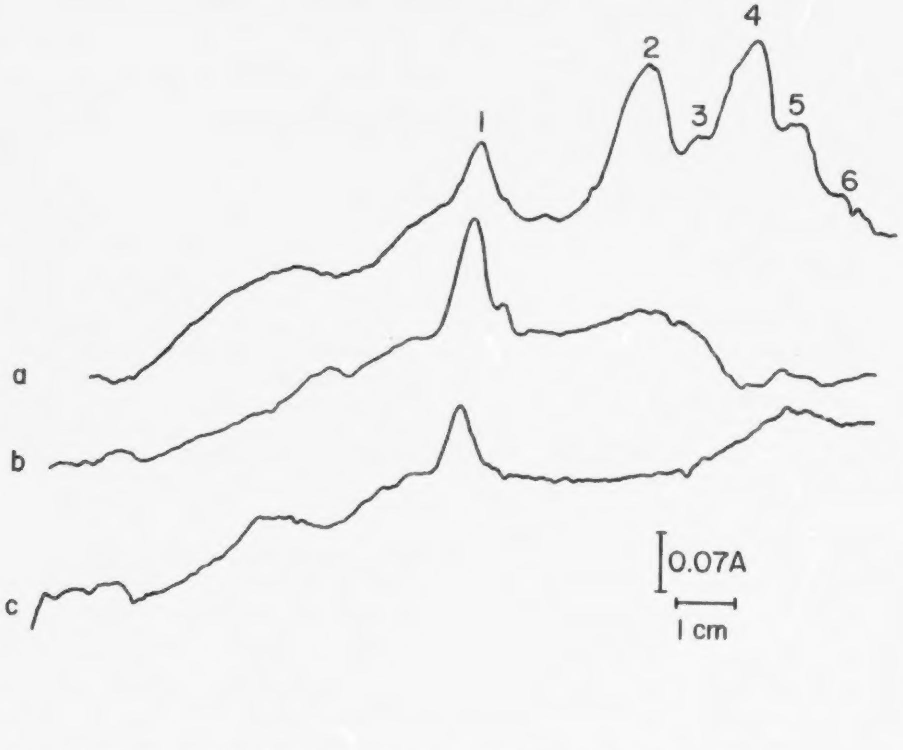

Figure 2.--Scans of polyacrylamide gels showing: a) isozymes of SOD in red spruce needles, b) a gel soaked in KCN, c) a gel soaked in H_2O_2 before staining.

It is also difficult to draw conclusions about the importance of the H_2O_2 effect. While there would seem to be cause for concern that 58% of the SOD activity is lost, this may not be physiologically relevant. There are matrix effects to consider since when exposed to 20 mM H_2O_2 in the gel all 5 isozymes were lost in an hour, but at 10 mM H_2O_2 in aqueous solution, only 2 isozymes were inhibited. This hydrogen peroxide level is also about three orders of magnitude higher than the levels found in clouds, but the trees are shrouded in fog for much longer periods of time. There is also the question of subcellular localization, since different isozymes are found in different compartments (Baum an Scandalios, 1981) and a peroxide sensitive isozyme would be much better protected in the chloroplast than it is in the periplasmic space. The final consideration is peroxidase activity. For these reactions, the peroxidase was inhibited with KCN. In the needles, peroxidase would provide protection against hydrogen peroxide. However, with these limitations in mind, two points should be made. The first is that a pollutant might not only affect growth. In studying the effects of air pollutants on plants, research should also examine the possibility that a plant's defenses against other pollutants are being damaged before there is any gross physiological affect. The other point is that measuring the total enzyme activity may not give the complete picture. Some isozymes might survive very well while others are completely lost, making some cell compartments much more susceptible than others to later injury.

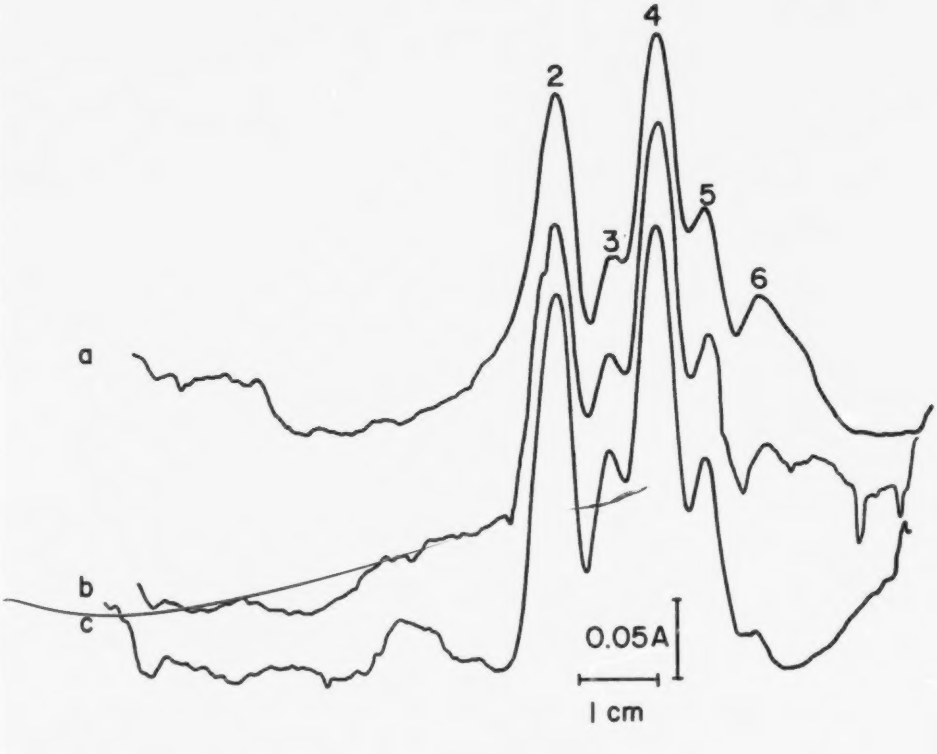

Fig. 3.--Scans of gels of "unfiltered" needles (Fig. 1): a) August, b) October, c) a seedling from the Duke Greenhouse.

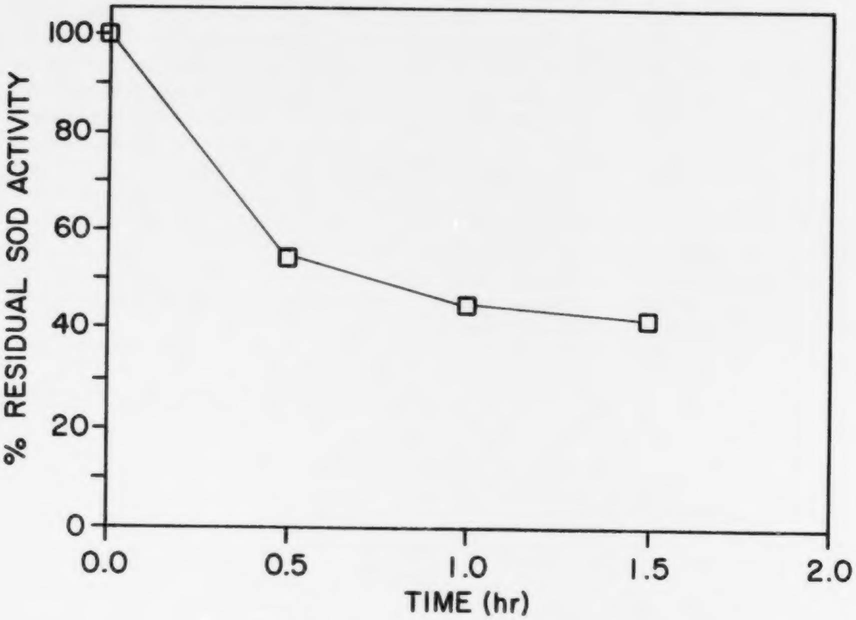

Figure 4.--Percent of SOD activity remaining in an H_2O_2 treated extract of red spruce needles.

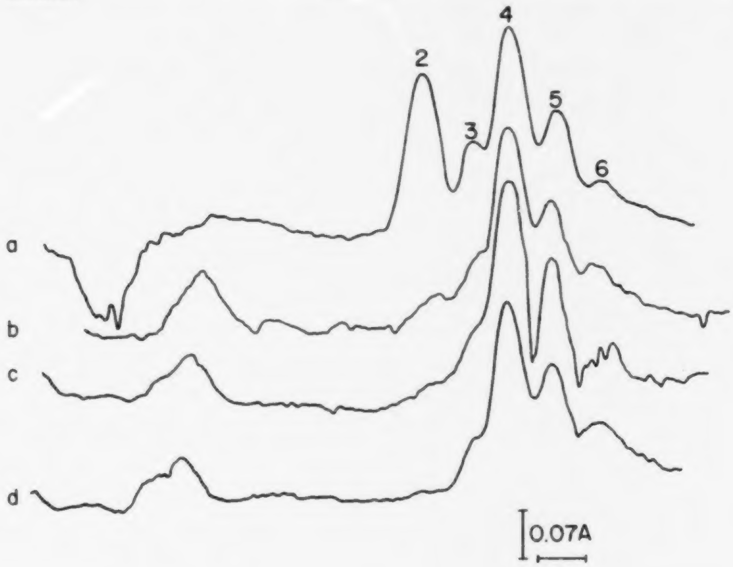

Figure 5.--Scans of polyacrylamide gels showing the SOD isozymes remaining at each time point on fig. 4: a) 0 hr., b) 0.5 hr., c) 1.0 hr., d) 1.5 hr.

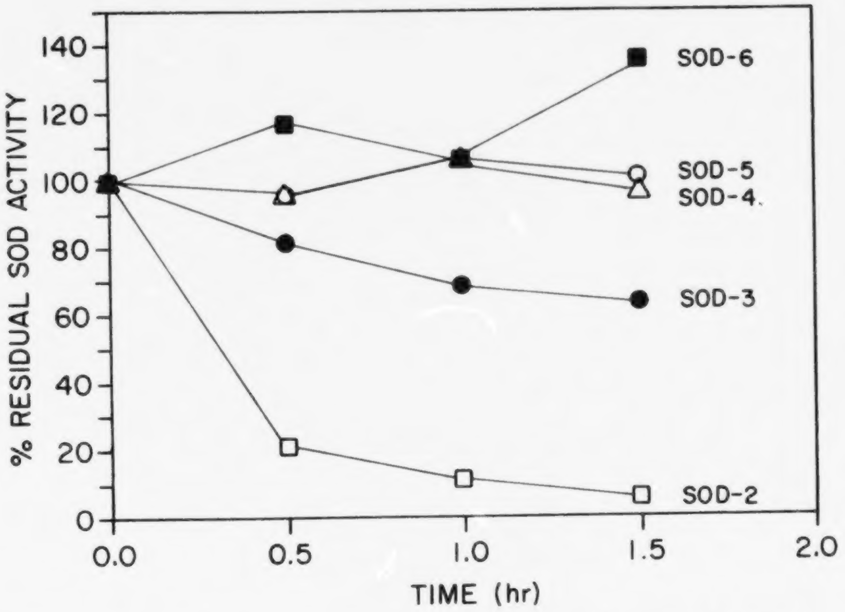

Figure 6.--Percent of SOD activity remaining in each isozyme of SOD in the H_2O_2 treated extract (Fig. 4), estimated from the peak heights in Fig. 5.

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Response of Red Spruce to Sulfur- and Nitrogen-Containing Contaminants in Simulated Acidic Mist

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Abstract

Seedlings of red spruce (Picea rubens Sarg.) were exposed repeatedly to simulated acidic mist for 35% of the hours during the growing seasons of 1985, 1986, or 1987 to test hypotheses concerning the effects of acidity, sulfate, and nitrate on foliar necrosis and persistence; shoot growth, development, and cold tolerance; and levels of foliar macro- and micro-elements. The combination of high acidity and high sulfate in mist was more toxic to foliage than the combination of high acidity and high nitrate. Visible necrosis of needles occurred at pH 2.6 and below but not at pH 2.8 and above. However, growth, bud-break, bud-set, and cold tolerance were unaffected. Levels of macro-elements in current-year needles were unaffected. For the micro-elements, significantly less iron and aluminum were found in needles of plants exposed to the combination of high acidity and high sulfate. Specific research recommendations are provided to improve relevance of these experiments to red spruce growing in montane forests of eastern North America.

Introduction

By the year 1990, the National Acid Precipitation Assessment Program (NAPAP) is obligated to provide first-order answers to questions about the relationship between acidic deposition and associated oxidants on the decline of red spruce (Woodman and Cowling 1987). To accomplish this goal, we and other scientists in the Spruce-Fir Research Program have been carrying out experiments in which seedlings are exposed to controlled levels of pollutants. Progress for one set of these controlled experiments is presented in this report in relation to the following scientific questions:

I. Is the acidity of ambient precipitation in high elevation forests in eastern North America sufficient to injure foliage of red spruce?

II. Do the sulfur- and nitrogen-containing components of wet deposition have similar effects on foliage when present in combination with high levels of acidity?

III. Is prolonged exposure to the sulfur- and nitrogen-containing pollutants in acidic mist likely to affect the growth, phenology, or cold tolerance of red spruce?

IV. Is prolonged exposure to the sulfur- and nitrogen-containing pollutants in acidic mist likely to alter nutrient levels in foliage of red spruce? The questions are being evaluated in the context of effects of acidic mist through contact with foliage rather than through changes in soil conditions.

Two facts provide the basic rationale for the experiments described in this report: 1. both sulfur and nitrogen are essential elements for plant growth and 2. sulfur and nitrogen are two of the most abundant components of acidic precipitation (Jacobson 1984). Both the concentrations of acidity in precipitation and the total deposition of acids to high elevation forests are greater than for other ecosystems in North America (Lovett et al. 1982). Therefore, a determination of the risk of harmful effects on foliage of indigenous trees is needed. Knowledge of any differences between effects of sulfur and nitrogen pollutants in precipitation also in needed because the U.S. Environmental Protection Agency already has regulations concerning emissions of sulfur- and nitrogen-containing pollutants and legislative bills and control strategies under consideration specifically identify additional limits on either sulfur or nitrogen oxide emissions or both (U.S. General Accounting Office 1984). Additional reasons for comparing the effects of sulfur- and nitrogen-containing pollutants in acidic precipitation are that individual events vary in the ratios of these pollutants and rates of leaching of foliar nutrients may be affected by the composition of precipitation (Krause et al. 1983).

Controlled experiments were conducted to test specific hypotheses relating to the acidity and anion composition of wet deposition. Certain features of the ambient situation at higher altitudes of eastern North America that are most directly related to the scientific questions under study were used as components of the experimental approach. The features selected for inclusion in these experiments were: provenances of the species, red spruce; the acidity (pH 2.5 to 4.2) and principal sulfur- and nitrogen-containing pollutants in acidic precipitation (sulfate, nitrate, and ammonium ions); the high proportion of hours with precipitation at higher altitudes of eastern North America (about 35%); and the phenological cycle of growth, dormancy, and regrowth.

The phenological cycle is a critical component of this research for two reasons. Shoot and needle growth potential is determined during the year previous to growth. Also, delayed development of dormancy due to uptake of components of precipitation by foliage might increase the risk of injury from cold temperatures during the ensuing winter.

Materials and Methods

In 1985, two provenances of dormant 3-0 red spruce seedlings were obtained, one from Vermont (supplied by Dr. M.W. Williams, Northeastern Forest Experiment Station, Burlington, VT) and the other from the Adirondack Mountains in New York (supplied by New York State Department of Environmental Conservation, Lafayette Road Field Station, Syracuse, NY). In

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1986, one provenance of dormant 3-0 red spruce seedlings was obtained from Vermont (seed lot no. VT 70-C supplied by Dr. Tim Demeritt, Northeastern Forest Experiment Station, Durham, NH). In 1987, one provenance of dormant 3-0 red spruce seedlings was obtained from New York (New York State Department of Environmental Conservation) grown from seeds collected at the Panther Brook drainage area of the Adirondacks near Newcombe, NY. Seedlings were transplanted into 25.4 cm deep x 6.4 cm diameter plastic conetainers with a rooting medium of ⅓ peat moss, ⅓ Perlite, and ⅓ loam soil in 1985 and 1986, and ½ peat moss and ½ Vermiculite in 1987.

Fertilizer addition in 1985 and 1986 was 2.8 kg/m^3 Osmocote 14-14-14, 2 kg/m^3 Peters fritted trace elements. In 1987, fertilizer addition was 4.4 kg/m^3 MagAMP, and 94.5 g/m^3 Osmocote 14-14-14, 3.0 kg/m^3 lime (containing 1.2% Mg), and 74 g/m^3 Peters fritted trace elements.

Seedlings were placed in a cool, shaded location to reduce the impact of transplanting. The size and appearance of all seedlings were evaluated to eliminate very large and very small plants and those with necrotic or missing needles, dead buds, and a needle morphology or color that was not typical of red spruce. Only healthy seedlings were assigned to chambers randomly within size groups so each chamber would have a representative plant from each size group.

Plants were not fertilized during the growing season and were irrigated with deionized water. Although deposition of simulated mist into the narrow conetainers was slight in 1985 and 1986, loose-fitting plastic covers were placed over the conetainers in 1987 to exclude deposition of mist to the soil medium. Seedlings were watered with deionized water by an automatic watering system once a week in 1987.

Every growing season, a new set of seedlings was exposed to simulated mist in 40 field chambers. Ambient precipitation was excluded from the field site with a mechanized overhead canopy that deployed over the field at the onset of a rain event and retracted at its termination (Troiano et al. 1984). Chambers were 90 cm tall and 80 cm in diameter and each chamber contained between 20 and 24 seedlings. Conetainers with seedlings were buried in rooting medium flush with the soil surface and treatments were assigned randomly to chambers. There were four replicate chambers for each of the nine treatments (three levels of acidity and three anions) and four chambers which received no mist at all. Each chamber contained a system for generating mist that included a plastic container for the mist solution, tubing to deliver solutions to the mist generator, and a Mini-Ulva spinning-disc device situated 60 cm above ground. During periods of mist generation, plastic curtains were drawn around and over each chamber to minimize the effects of wind on mist distribution. Mist was generated at about 0.1 cm/hour beginning in the late afternoon and continuing, without interruption, through the night four times per week. Water content of chamber atmospheres was measured rather than deposition because droplets were too small (about 20 μm) to sediment rapidly. Air was drawn at 1 liter per minute through a pre-weighed polyethylene tube 32 cm in length and 4 cm in diameter that contained 3 g of glass wool. The tube was placed horizontal to the ground at canopy height. After about 16 hours, the polyethylene tube containing glass wool was weighed again and water content expressed in g/m^3. Conditions for exposure of seedlings to mist are summarized in Table 1. The levels of acidity, chemical components, and their concentrations in simulated mist (Table 2) were selected to encompass the range from above to below the concentrations occurring in cloudwater.

Foliar injury was scored by a single experienced individual at intervals during the growing season and once the following spring for seedlings that remained in the field over winter. Each seedling was scored for the number of needles with necrotic lesions according to the following scale in 1985 and 1986 (change in scale indicated in parentheses for 1987 observations): 0: no needles injured, 1: less than 5% of needles injured (1-10%), 2: 5 to 15% of needles injured (10-15%), 3: 15 to 35% of needles injured (25-50%), 4: 25 to 65% of needles injured (50 to 75%), 5: 65 to 85% of needles injured (75 to 90%), and 6: 85 to 95% of needles injured (more than 90%). This system is based on the tendency of visual observations to be more precise toward the extremes rather than the middle of the scale (Horsfall and Cowling 1978).

Extension growth of leader shoots was measured at intervals during the growing season on five randomly-selected seedlings per chamber. Volume displacement of the aboveground tissues was measured at the beginning and end of the period of treatments (Glerum and Boufford 1979). Measurements of phenological development were made during the late summer and fall (bud-set) and during the following spring (bud-break) for seedlings that remained in the field over the winter. Bud-break was scored on upper, lateral shoots according to the following scale: 0: no swelling of buds, 1: swelling of buds, 2: green color of needles visible on less than 50% of buds, 3: green color visible on more than 50% of buds, 4: needles beginning to separate from each other, 5: needles fully separated, and 6: shoot elongating. In 1985, bud-set was determined simply by recording the presence or absence of buds on leader shoots of each seedling. In 1987, bud-set was determined by removing buds from upper lateral shoots of one seedling per chamber, removing bud-scales, and counting the number of rows of needle primordia under a binocular microscope (Colombo et al. 1982).

Cold tolerance was evaluated (Colombo et al. 1984) by removing the distal 4 cm (current needles only) of five lateral shoots from the upper portion of one seedling per chamber. Shoots were rinsed under a stream of deionized water to remove surface contamination and allowed to dry at room temperature. Length and fresh weight of each shoot were recorded. Each shoot then was placed in a plastic scintillation vial with a tightly-sealed cap. Vials were placed in a refrigerated chamber programmed to decrease temperature to five preset values at a rate of 4 degrees per hour. One set of vials from each group of five shoots per seedling was removed from the cold chamber after the first below-freezing temperature was maintained for one hour. These vials

Table 1.--Summary of conditions for exposure of red spruce seedlings to simulated acidic mist in field experiments

Item	1985	1986	1987
Date of initiation of mist exposures	5Aug	30June	22June
Duration of treatment period, days	57	88	117
Total duration of treatment, hours	473	698	1040
Proportion of days with mist, %	56	57	57
Proportion of hours with mist, %	35	33	37
Water content of atmosphere, g/m^3	-	-	0.49
Total amount of water supplied to each chamber, cm	40	43.6	105

Table 2.--Concentrations of components of simulated acidic mist used in field experiments with red spruce seedlings

		Mist A[1]	Mist B[2]		Mist C[3]		
Year	pH	Sulfate	Nitrate	Ammonium	Sulfate	Nitrate	Ammonium
				µmole/liter			
	2.5	1580	3160	-	1050	1050	-
1985	3.5	160	320	-	105	105	-
	4.5	16	32	-	11	11	-
	2.8	790	1580	-	530	530	-
1986	3.5	160	320	-	105	105	-
	4.2	32	63	-	21	21	-
	2.6	1260	3770	1260	840	1260	420
1987	3.4	200	600	200	130	200	65
	4.2	32	95	32	21	32	11

[1] Sulfuric acid alone.

[2] Nitric acid alone (1985 and 1986) or with ammonium nitrate (1987).

[3] Mixture of sulfuric and nitric acid (1985 and 1986) or with ammonium nitrate (1987).

were placed in an insulated container in a refrigerator at 4 °C for slow warming. The cold chamber then was programmed to decrease temperature to the second, third, fourth, and fifth preselected below-freezing temperatures. Vials were removed after one hour at each of these temperatures and kept in the refrigerator for at least 1 hour before measurements of conductivity were performed.

To measure leakage of ions, shoots were removed from vials and placed into individual 150 ml plastic cups with 25.0 ml 0.02% Triton X-100 wetting agent. Cups were covered with aluminum foil and placed on a rotary shaker for overnight extraction at room temperature (20-22 °C). Cups containing only the wetting agent also were placed on the shaker to establish blank values. Conductivity of all solutions was measured with a calibrated conductivity cell and meter at room temperature. All samples then were placed in an autoclave at 121 °C for 20 minutes and conductivity again was measured after samples were allowed to cool. Relative conductivity was calculated according to the following formula: [initial cond. ÷ final cond.] X 100 (Colombo et al. 1984).

Temperature of the cold chamber was checked with a thermometer traceable to an NBS reference standard. The conductivity cell and meter were calibrated with 75, 200, and 720 µmho standard solutions.

For elemental analyses, current-year shoots were excised in October, rinsed with deionized water to remove surface deposits, and dried in a force-draft oven at 80 °C for 48 hours. Needles then were separated from stems and placed in labelled plastic containers. Needles were not pulverized to avoid contamination with elements from metallic blades or sieves. Nitrogen analyses were performed by a micro-Kjeldahl method. For other elements, samples were dry-ashed and analyzed by inductively-coupled argon plasma-atomic emission spectroscopy. All analyses were performed in the Department of Pomology, Cornell University.

Data were placed in computer files with hard-copy backup and checked against original data sheets. Summary statistics were calculated and analyses of variance performed, using a 3 by 3 factorial design, with programs of SAS (Statistical Analysis System, version 5.16). A probability level of 0.05 or less was used to reject the null hypothesis. The experimental unit was an individual chamber so statistical analyses were performed on mean values derived from measurements performed on one or more seedlings per chamber.

Results

Needles of red spruce seedlings developed foliar injury after repeated exposures to the highest levels of acidity during the summers of 1985 and 1987 (Table 3) but not in 1986 (data not shown). In the fall of 1985, there was a strong acidity by anion interaction (Table 4) with the highest sulfate treatments exhibiting more needle necrosis than the sulfate/nitrate treatment which had more injury than the nitrate alone (all at pH 2.5). By the spring of 1986 (after a winter of no treatment and exposure to ambient conditions), the acidity by anion interaction disappeared but the effect of acidity remained on one of the two provenances. Neither loss of needles during the winter nor bud-break during the spring of 1986 were affected by treatment. Similar measurements taken during the spring of 1987 for seedlings exposed during the summer of 1986 also showed no significant effects of treatment (data not shown).

Leader growth measurements demonstrated a normal pattern of slow growth early in the season, then rapid growth, and finally a slowing of growth toward the end of summer (Table 5). No significant effects of treatment were found in 1985 or 1986 (data not shown) nor were effects significant in 1987 (Table 5).

Measurements of electrolyte leakage of shoots after exposure to below-freezing temperatures demonstrated that the expected increases in relative conductivity with decreasing temperature occurred for three of the four dates tested (Table 6). On November 20, 1986, cold tolerance of shoots was under-estimated and break-through of electrolytes from frozen tissue was not achieved. The only result with $p < 0.05$ was obtained on April 24, 1987 (an acidity X anion interaction). The general lack of significant effects indicates that electrolyte leakage was not affected by treatments.

Treatments did not significantly affect levels of macro-elements. The only micro-elements affected by treatments were iron and aluminum (Table 7) each of which averaged about 40 ppm lower in treatments containing the highest level of sulfate. Although analyses of National Bureau of Standards (NBS) reference samples gave excellent results for most elements, values for iron and aluminum were low by 12 and 23%, respectively.

Discussion

Results of exposures of seedlings of red spruce to simulated mist in 1985 and 1987 suggest that the combination of high acidity and high sulfate in precipitation is more toxic to foliage than the combination of high acidity and high nitrate (with ammonium ions in 1987). These results are contrary to those obtained after exposure of radish and bean plants to simulated rain with different anion composition (Jacobson et al. 1986; Trites and Bidwell 1987). However, indication of harmful effects resulting from the accumulation of sulfur in woody plants has been reported in Finland (Havas and Huttunen 1980). Two alternative, but not mutually exclusive, hypotheses can be suggested to explain these initial results with red spruce: 1. the presence of high sulfate in precipitation enhances the toxicity of acidity and 2. the presence of high nitrate (and/or ammonium ions) in precipitation increases tolerance to the toxic effects of acidity. Sulfate may enhance toxicity by accelerating the leaching of calcium and magnesium. Nitrogen may reduce toxicity by increasing assimilation and raising the capacity of foliar tissues to metabolize protons and control internal acidity. Research should be performed to test these hypotheses and to develop quantitative dose-response relationships for sulfate, nitrate (and ammonium ions), hydrogen ion concentrations, and plant response.

The lack of visible injury to needles of red spruce after exposure to simulated precipitation at pH values of 2.8 or higher is consistent with previous reports (Taylor et al. 1986). The inability to detect effects on growth even when necrosis of foliage has occurred has been reported previously for other types of vegetation (McColl and Johnson 1983; Jacobson et al. 1987) and may be explained in several ways. First, measurements of foliar injury usually have lower relative standard deviations than measurements of growth so detection of foliar symptoms is easier than for growth. Second, the maximum amount of foliar injury found in these tests was 10 to 25% of the needles per seedling

Table 3.--Effects of acidity and sulfur- and nitrogen-containing components of simulated mist on foliar injury and bud-break of seedlings of red spruce

Item	Low acidity[1]			Medium acidity[1]			High acidity[1]		
	S	N	S/N	S	N	S/N	S	N	S/N
	Mean % of Needles Injured (Fall 1985)								
Red spruce NH	2.5	1.3	1.3	1.3	1.3	1.5	12.6	2.4	5.6
Red spruce Syr.	1.1	0.5	1.3	1.3	0.9	1.6	21.7	2.0	3.0
	Mean % of Needles Injured (Spring 1986)								
Red spruce NH	1.1	0.7	1.5	1.4	1.0	1.0	2.9	1.9	2.5
Red spruce Syr.	2.8	3.2	3.8	3.9	2.8	6.3	6.1	3.0	9.2
	Mean % of Needles Injured (Week 11 1987)								
Red Spruce	-[2]	-[2]	-[2]	-[2]	-[2]	-[2]	21.0	2.7	6.4
	Bud-break Score (Spring 1986)								
Red spruce NH	1.7	1.8	1.4	1.8	1.7	1.3	1.3	1.2	1.0
Red spruce Syr.	1.1	1.2	1.1	1.2	1.0	1.1	1.3	1.1	1.0
	Bud-break Score (Spring 1987)								
Red spruce	1.8	1.9	1.8	1.8	1.7	1.7	1.8	1.7	1.9

[1] See Table 2 for levels of acidity for each year.

[2] Injury of less than 1% was not included in statistical analyses.

Table 4.--Analysis of variance for foliar injury and bud-break of red spruce seedlings exposed to sulfur- and nitrogen-containing components in acidic mist

Item	Probability level		
	Acidity	Anion	Acidity X Anion
	Foliar Injury (Fall 1985)		
Red spruce NH	0.0001	0.0018	0.0019
Red spruce Syr.	0.0001	0.0008	0.0001
	Foliar Injury (Spring 1986)		
Red spruce NH	0.0002	0.15	0.78
Red spruce Syr.	0.25	0.14	0.74
	Foliar Injury (Week 11 1987)		
Red spruce	-	0.001	-

Table 5.--Effect of acidity and sulfur- and nitrogen-containing components of simulated mist on growth of leader shoots of seedlings of red spruce in 1987

Week of exposure	Cumulative mean growth, cm	Probability level		
		Acidity	Anion	AcidityXAnion
2	0.36	.64	.39	.42
4	0.70	.94	.44	.39
6	1.50	.85	.43	.44
8	2.53	.79	.69	.59
10	3.00	.92	.76	.59
12	3.07	.95	.77	.54

Table 6.--Effects of acidity and sulfur- and nitrogen-containing components of simulated mist on cold tolerance of shoots of seedlings of red spruce

Date	Temperature,°C	Relative[1] conductivity	Probability level		
			Acidity	Anion	AcidityXAnion
9/24/86	-8.0	3	.22	.06	.44
	-11.3	13	.56	.32	.21
	-14.9	30	.22	.35	.72
	-18.5	40	.86	.31	.57
	-22.1	49	.81	.37	.57
11/20/86	-10.9	4	.68	.82	.61
	-14.8	4	.45	.40	.55
	-18.8	3	.07	.69	.96
	-22.7	4	.27	.57	.21
	-27.0	7	.86	.49	.25
4/1/87	-15.7	4	.78	.24	.24
	-20.5	6	.55	.44	.41
	-25.6	7	.57	.32	.28
	-30.5	10	.63	.74	.34
	-35.8	20	.58	.75	.62
4/24/87	-15.9	16	.58	.32	.30
	-25.6	32	.88	.64	.15
	-35.4	38	.72	.09	.02

[1] Initial conductivity expressed as percent of conductivity after autoclaving.

Table 7.--Effects of acidity and sulfur- and nitrogen-containing components of simulated mist on elemental composition of current-year foliage of red spruce seedlings in 1986 field experiment

Element	Mean concentration	Percent of NBS[1]	Probability level: Acid	Anion	AcidXAnion
Nitrogen, %	2.0	100	.39	.96	.143
Phosphorus, %	0.24	98	.87	.53	.27
Potassium, %	0.92	96	.08	.93	.27
Calcium, %	0.47	107	.65	.72	.98
Magnesium, %	0.24	-	.15	.87	.82
Manganese, ppm	1200	104	.09	.58	.37
Iron, ppm	184	88	.59	.003	.43
Aluminum, ppm	152	77	.82	.001	.37
Zinc, ppm	53	-	.69	.33	.60
Copper, ppm	2.6	107	.72	.86	.21

[1] Analysis of National Bureau of Standards Reference Pine Sample No. 1575 reported as percent of NBS value.

which may not have affected growth of current-year shoots. Alternatively, injury to some needles may have accelerated assimilation rates and growth of healthy tissues compensating for the injury (Trites and Bidwell 1987). Finally, it is common for biomass of belowground tissues in other species to be affected more severely than aboveground tissues even when only the aboveground tissues are exposed to simulated acidic precipitation (Jacobson et al. 1986). Future tests will include measurement of root as well as shoot biomass and other changes designed to improve evaluation of effects on growth and development.

Plants growing under extreme climatic conditions near the limits of their survival are highly vulnerable to changes in environmental conditions (Havas and Huttunen 1980). They may be more sensitive to effects of pollution than plants growing under less stressful conditions. A delay or acceleration of plant development may desynchronize plants from the local climatic conditions and alter their capacity to survive from marginal to sub-marginal. However, initial results from these experiments have not demonstrated a delay in bud-set, an acceleration of bud break the following spring, or decreases in cold tolerance as a result of exposure to simulated acidic mist. Measurements of carbon dioxide assimilation performed on seedlings in 1987 not presented in this report indicate a trend toward higher photosynthetic rates in seedlings exposed to mist at the highest levels of acidity and nitrogen-containing components. The consequences of increased assimilatory activity toward the end of the growing season need further evaluation. Continued research on this subject is warranted before conclusions can be drawn concerning effects on phenology and cold tolerance.

One of the most widely discussed hypotheses of decline of spruce in Europe involves accelerated leaching of nutrients by acidic precipitation and ozone (Krause et al. 1986). Increased loss of nutrients from foliage by acidic precipitation has been demonstrated but, in many cases, no concomitant reduction in nutrient content of the foliage was found suggesting accelerated root uptake of nutrients from the soil. Our initial results of foliar analysis indicate decreases only in levels of iron and aluminum, two elements commonly present in soil particles found as contaminants on foliage. This finding suggests the need for removal of foliar surface contaminants before elemental analyses of foliage are made for components that have physiological significance (Wyttenback et al. 1985; Krivan et al. 1987). It also raises the question of differences between levels of elements in foliage of plants grown under artificial conditions and foliage of trees growing in forested locations.

Comparisons with published levels of elements in native red spruce trees (Friedland et al. 1988) suggest that the levels of nitrogen, potassium, magnesium, iron, and aluminum were elevated in current-year needles of seedlings used in this study. Amounts of nutrients added to the rooting medium will be decreased in future experiments to provide foliar nutrient concentrations closer to those found for red spruce in the forest. Sulfur analyses, that include both total sulfur and soluble inorganic sulfur, also are being performed on foliage to determine whether sulfur levels increase as a result of exposure to acidic mist. Soluble inorganic nitrogen as well as total nitrogen also is being measured.

A critical issue for all controlled experiments with simulated precipitation is the extent to which penetration of acids into foliage and leaching of nutrients from foliage is comparable to that occurring in needles of red spruce trees growing in the forest. If penetration and leaching occurs at lower rates in controlled experiments, then conclusions concerning the risk of foliar injury from acidity and foliar nutrient deficiencies from leaching will be underestimated. Observations made during the summer of 1987 for ambient precipitation on needles of red spruce growing in the Adirondacks suggests that their wettability is much greater than that of needles on seedlings in controlled experiments. Both penetration and leaching of solutes may be promoted by increased wettability (Boynton 1954; Skoss 1955). Measurements of leaf water-holding capacity and contact angles of droplets have been suggested as first indicators of response to acidic rain (Haines et al. 1985). Data on leaf wetness from Whiteface Mountain (Personal Communication, Jeanne Panek, Mountain Cloud Chemistry Program) indicate that there are frequent wet-dry cycles at higher elevations providing more opportunities for evaporation of liquid on leaf surfaces in nature than in controlled experiments. Evaporation of precipitation increases solute concentrations on leaf surfaces (Unsworth 1984; Jacobson 1984). Decreases in pH of at least one full pH unit during evaporation of droplets have been reported (Klemm et al. 1987) but neutralization of droplets on leaf surfaces also can occur (Hutchinson et al. 1985). We measured pH values of 1.6 in evaporating droplets on needles of red spruce seedlings which had been exposed to simulated mist in the greenhouse at pH 2.6, suggesting that red spruce needles have a low capacity for neutralization of acidity. The influence of wettability and wet-dry cycles on penetration of acids and leaching of nutrients require investigation in order to provide a more rigorous basis for evaluating the significance of acidic precipitation for the growth and survival of red spruce.

Recommendations

In order to determine whether first-order evaluations underestimate the risk of harmful effects of acidic deposition on red spruce trees growing in the forest, the following research should be performed: 1. continued evaluation of the separate and combined effects of the sulfur- and nitrogen-containing components in acidic precipitation, 2. investigation of the wettability of foliage of red spruce and the influence of differences in wettability on toxicity and nutrient levels when foliage is exposed to acidic precipitation, 3. investigation of the influence of intermittent wet-dry cycles on toxicity and nutrient levels of foliage, and 4. development and application of methods for the removal of surface contaminants from foliage prior to elemental analyses.

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Interactive Effects of Natural and Anthropogenic Factors on Growth and Physiology of Southern Red Spruce

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Abstract

Field and laboratory studies are underway to characterize physiological changes associated with the decline of red spruce (Picea rubens Sarg.) at high elevations in the Great Smoky Mountains National Park. Two research plots have been established on Cingman's Dome (1720 m and 1935 m elevations) to document the magnitude of growth changes at sites experiencing varying degrees of growth decline and to explore the physiological basis of observed differences. The objective of this approach is to evaluate likely mechanisms of action and identify natural and anthropogenic factors influencing the observed growth patterns. Field measurements include historical and current radial growth of mature trees and saplings, and seasonal patterns of carbon assimilation, carbon allocation, and water relations of saplings. Laboratory experiments include dose response exposures with H_2O_2, toxicity screening studies with Al, Mn, and Ca, and characterization of the foliar uptake and metabolism of nitrogen oxides.

Introduction

A central issue in the evaluation of potential air pollution effects on forests in North America has been the decline of red spruce in the Appalachian Mountains of the eastern United States. Recent reviews of the symptomology, ecology, and distribution of red spruce decline in the northeastern United States (Burgess et al. 1984, Johnson and McLaughlin 1985) provide inferential evidence that the phenomenon differs in some respects from previous forest declines reported for some spruce stands in the Northeast during the last part of the 19th century.

A recent analysis of a regional data set on radial growth and mortality of red spruce in the eastern U.S. (McLaughlin et al. 1987) focused on the historical precedents for observed patterns of decreasing radial growth and their relationship to climate and competition. Collectively, these analyses indicate that the observed growth decreases of surviving red spruce trees at northeastern sites with high mortality have been anomalous during the past 20 to 25 years with respect to both historical annual growth patterns and past relationships to climate or stand development at these sites. In general, reductions in radial increment that have also been noted at southern high elevation sites, but not at lower elevations (below 1500 m), occurred 5 to 10 years later than at northern sites and represent less substantive departures from growth trends predicted by linear climate models.

These analyses suggest that regional and not local stresses have triggered the observed decline in radial growth of red spruce at these sites. While climatic change may have contributed to observed changes, the degree of radial growth suppression observed is greater than would be expected based on past growth-climate relationships. This unusual relationship of growth to climate observed in recent years suggests either recent, unique combinations of climatic stresses or the possibility of interactive intervention of other regional-scale stresses, such as atmospheric pollution.

In spite of several types of inferential evidence that atmospheric pollutants may be contributing to observed declines, there is currently no experimental data that can causally link these changes to pollution. Principal mechanisms are not clearly established; pollution histories are not well documented; and interactions amongst environmental modifiers are complex. Until mechanisms of action are documented and a better understanding is provided of the interactions between growth, ambient levels of individual and combined pollutants and principal natural environmental modifiers, linkages between pollutants, and observed growth declines will remain correlative, indirect, and less than satisfactory as a basis for evaluating the need for regulatory action.

This research focuses on characterizing changes in physiological properties of red spruce growing in areas where growth change has been observed and on examining plant responses to two recently-recognized pollutants of potential risk to vegetation growing at high elevation sites. Collectively, these exploratory studies are designed to provide a mechanistic basis for identifying physiological responses and evaluating the probability of cause-effect relationships between exposure to ambient pollutant levels and observed responses of vegetation in the field.

Research Strategy

There are two major operational objectives and two principal hypotheses around which this research plan has been developed. The objectives are: (1) to identify and quantify some important physiological processes of red spruce growing in the field in stands showing differing degrees of radial growth suppression, and (2) to test physiological and growth effects of hydrogen peroxide (H_2O_2), foliar-deposited nitrogen, and two soil-derived toxic metals (Al and Mn) on red spruce seedlings under controlled laboratory conditions.

The two principal hypotheses to be tested in this research were formulated around principal mechanisms of effects of pollutants

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on forest health: (1) ambient pollutant levels have led to decreased vigor of high elevation red spruce primarily through direct effects on the physiology of foliage, specifically on carbon and nitrogen metabolism; and (2) reduced growth of red spruce is principally a function of indirect effects of pollutants on vigor and function of the belowground system, and reduced uptake of water and nutrients.

Research Progress

Work within this project has proceeded in six areas during FY 1987. Specific objectives, methods, and preliminary results to date from these activities are summarized below.

Growth Trend Characterization

Objective. To quantify differences in red spruce growth and associated site characteristics along an elevational gradient where differences in radial growth decline have occurred.

Approach. Two primary sites (1720 m and 1935 m) were selected for growth and physiological studies. Measurements of height, diameter, and growth in height and diameter for each of the past five years were obtained for 30 2 m-tall saplings at each site. Ten dominant trees were cored and measured in 5-year intervals for the past 50 yr to establish longer term growth trends, and dendrometer bands were placed around each tree for approximately bi-weekly diameter measurements to establishing seasonal growth trends. Since a primary interest of this study was characterizing and better understanding patterns of unusually slow growth, the 10 trees at each site were separated into groups of 5 that showed the most or least growth decline at respective sites.

Additional measurements of growth related parameters on these sites include competitive status of each study tree; five surveys of potentially ectomycorrhizal sporocarps; and chemical analysis of soil and foliage.

Results. Growth-ring analysis of mature red spruce showed that radial growth of the most rapidly declining trees at each site had decreased more rapidly during the last 20 years at the upper site, but that the greatest relative decrease occurred during the past 5 years at the lower site as shown in Figure 1. Trees identified as "most" and "less" at each elevation represent the groups of 5 trees each showing the most or least pronounced indication of a radial growth slowdown in the past 20 years. A comparison of size, estimated age, and rates of slowdown of the fastest declining trees at each site shown in Table 1 reflects the quite comparable age and size of these trees that were selected for subsequent studies of changes in energy storage reserves. Dendrometer bands were placed on all 10 trees at each site and have proven sensitive enough, when read with digital calipers, to measure diurnal and seasonal changes in stem circumference (Figure 2). Growth trend data from the current growing season record similar growth patterns over both sites with the rapid surge in growth in June followed by two periods of slowdown, one during the period of rapid foliage growth and a second in August during a drought. Trees with the least previous growth decline grew fastest in the early spring regardless of elevation.

Table 1.--Summary characteristics and growth trend data for 5 trees having most apparent recent growth decline at upper (1935 m) and lower (1720 m) study sites

Characteristic	Upper site	Lower site
Diameter breast height (cm)	58.2	56.0
Estimated age (at dbh)	223	215
Total growth in 50 yrs (mm)	65.1	65.1
Total growth past 5 yrs (mm)	3.14	3.60
Growth past 5/30-50[1]	0.40	0.56
Growth past 20/30-50[1]	0.40	0.93

[1] Comparisons involve determining ratios mean radial growth rate between time intervals of specified length extending back from the present.

Analysis of height and diameter growth of 30 saplings on each site (Table 2) revealed that height growth during the last 5 years at the lower elevation site was approximately 55% greater than at the upper elevation site even though canopy coverage is greater and precipitation is lower at the lower site.

Carbon Metabolism

Objective. To test the hypothesis that differences in growth rates observed between sites are due to differences in alteration of carbon assimilation and distribution patterns by either episodic or chronic disturbances by atmospheric deposition.

Table 2.--Red spruce sapling growth data, average of 30 saplings on each the lower and upper sites. Each value is the mean and the standard error of 30 saplings.

Variable	Lower site	Upper site
Total height (cm)	184 ± 5	201 ± 8
Seedling diameter (mm)	28.3 ± 1.0	32.8 ± 1.7
Height last 5 yr (cm)	85.7 ± 3.4	65.2 ± 2.9
Height/diameter ratio	6.6 ± 0.15	6.3 ± 0.16
Relative height growth rate*	13.2 ± 0.7	8.1 ± 0.5
Stem volume - 5 yr**	6623.6	4100.4

*Calculated for individual saplings as ((log$_e$(totht)—log$_e$(totht 5 yrs ago))/5 yr) * 100. Units are cm/cm/yr.

**Calculated for each individual saplings as follows: vol = r^2 * height * π for each internode (volume calculation for a cylinder). The total volume for each of the 5 internodes was summed to calculate a total stem volume growth for those tissues for each tree during the last 5 years.

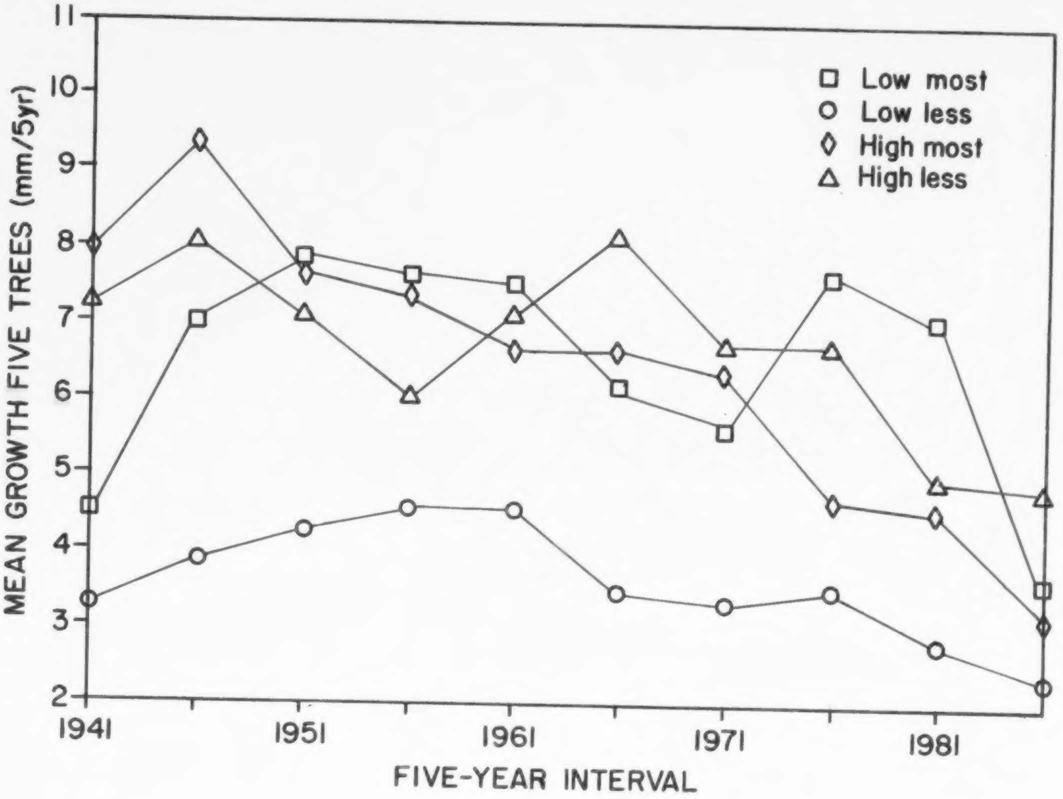

Figure 1.--Mean 50-year growth trends for groups of 5 trees each exhibiting the most or least recent growth slowdown at high (1935 m) and lower (1720 m) elevation study sites. Dates are the last year in each 5 year segment measured.

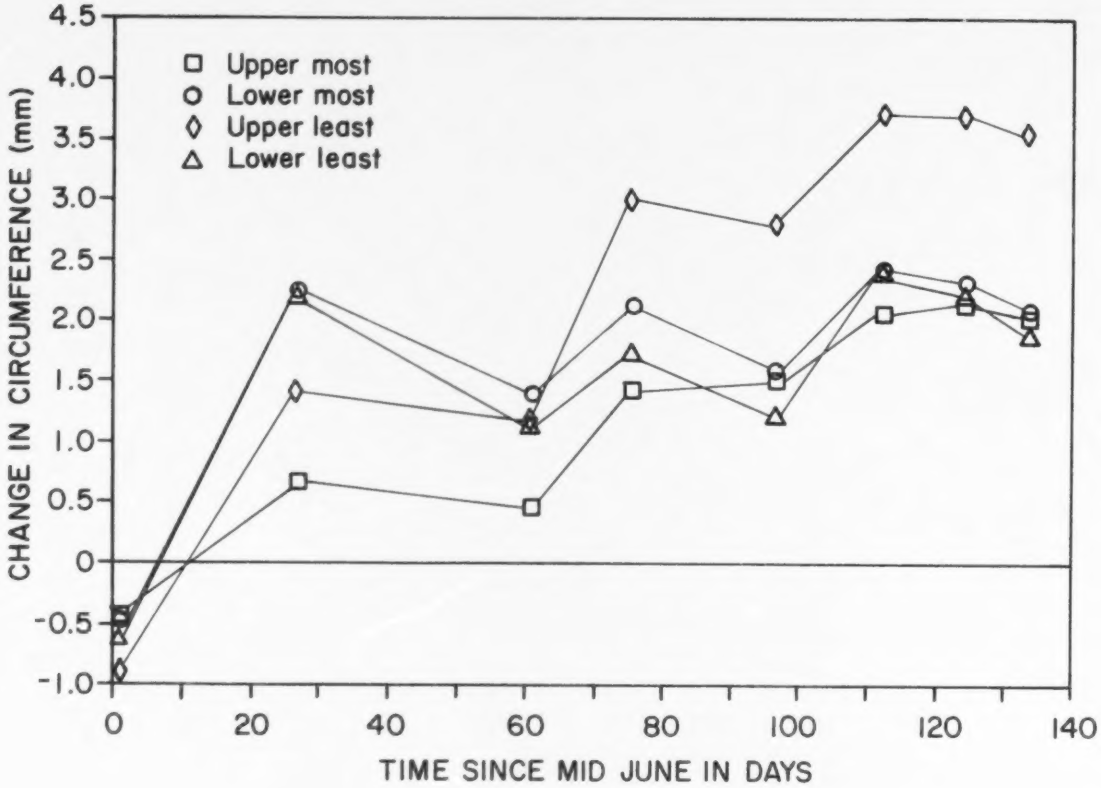

Figure 2.--Seasonal changes in stem circumference of a group of 5 trees each at each of two elevations (6350 ft and 5650 ft). Data are means derived from dendrometer bands. Each data point represents the accumulated change from initial measurements made during mid-May. Initial shrinkage is considered a consequence of band equilibration after installation in May.

Approach. Eight saplings representing mean growth rates at each of the two primary sites were selected for periodic remeasurement of gas exchange of 2 to 3 age classes of needles from two branches per tree. Measurements of photosynthesis (Ps) were made in June, July, August, September, and October using LiCor 6200 portable photosynthesis systems operating concurrently at both sites. Respiration (Rs) measurements were also made and light: Ps response curves were established in August and September. Carbon metabolism studies of 6 saplings per site were conducted in June, August, and October using C^{14} tag and resample techniques (McLaughlin et al. 1982) to follow metabolism of C^{14}-photosynthate at 1 and 7 days after photosynthetic uptake. Chlorophyll content of needle tissue was followed in comparisons between sites in September and October using DMSO extraction and spectrophotometric techniques described by Aiscox and Israelstam (1979). Samples of roots and boles of 5 dominant, previously-cored trees were collected for biochemical analysis of levels of lipids, starch, sugars, and structural carbohydrates in July at the peak period of energy demand. Samples will also be collected in November after carbon assimilation has diminished to dormant season levels.

Results. Preliminary analyses of gas exchange data for June and September (Table 3) indicate that, in June, carbon assimilation rates at light saturation (>1000 μmole m^{-2} s^{-1}) of both 1 yr old and 3 year old foliage were lower at the upper elevaiton site (-27% and -14% below lower site values, respectively). Differences in photosynthesis (Ps) were even more pronounced at low light levels (100-300 μmole m^{-2} s^{-1}) with 1 yr and 3 yr foliage having 55% and 36% lower capacity respectively at the upper site. Measurements in September indicated that saturation Ps values were comparable for 1 yr-old foliage, but that foliage of the current year was lower by 23% at the upper site. Accompanying measurements of respiration indicated a more favorable carbon balance for both age classes at the lower site evidenced by higher ratios of photosynthesis to respiration. Chlorophyll concentrations per unit weight of foliage measured in September (Table 4) were higher in seedlings at the lower site, consistent with observations of growth and carbon assimilation. These data indicate a generally reduced carbon assimilation capacity associated with slower growth at upper site; however, analyses of data for July, August, and October, coupled with measurement of carbon-14 distribution patterns, will provide a more complete picture of seasonal differences in carbon assimilation capacity.

Water Relations

Objective. To test the hypothesis that changes in root activity or water availability are playing a significant role in reduced physiological vigor of trees in which declining growth has been observed.

Approach. Sapling water relations have been examined in the field through pressure bomb readings of tissue water potential from 5 saplings per site 4 times, and branches have been returned to the laboratory for overnight rehydration and subsequent development of pressure:volume (p:v) curves (Ritchie and Roden, 1985, Method B) 4 times during the past year.

Results. Pressure-volume analysis of current year tissue revealed that saplings at the upper elevation site had significantly lower saturated osmotic potentials in July than saplings at the lower site, a condition typically associated with drought stress and accumulation of solutes and cell sap (Table 5). Differences in solute accumulation between sites diminished throughout the summer, and were not significantly different between sites in late September. During July and August saplings at the upper site also maintained cell turgor at lower relative water contents. Saplings did not show any increase in solute accumulation as late as September 29 in response to decreasing fall temperatures.

Hydrogen Peroxide Toxicity Screening

Objective. Determine effects of controlled levels of wet deposition on gas exchange characteristics (CO_2 and H_2O), needle chlorophyll concentrations, and growth of red spruce seedlings.

Approach. Controlled laboratory studies of the response of 1-0 red spruce seedlings to chronic H_2O_2 wet deposition were conducted over a 16 week period. Twenty-four seedlings per treatment were exposed to four concentrations (0, 0.5, 2 and 8 mg l^{-1}) of H_2O_2 fog (mist) three times each week throughout the experiment. A typical exposure began at midnight and continued until two hours after sunrise (0900 EDT). An exposure system similar to the one described by Masuch et al. (1986) was used. The fog solutions were made by mixing H_2O_2 from stock supplies with a solution having a pH 3.8 to 4.0 chemistry typical of high elevation fogs. All treatment solutions were mixed daily. Samples of the applied fog were monitored for H_2O_2 concentrations using the derivatization technique of Kok et al. 1986.

Measurements of height and diameter and observations of visual symptoms of needle damage were made approximately every 2 weeks, and three separate measurements of seedling gas exchange (photosynthesis, respiration and stomatal conductance) were made 2, 9, and 16 weeks after starting exposures. Photosynthetic measurements were made with a LiCor LI-6200/6250 portable photosynthesis system using the 1 liter cuvette. Final measurements of plant dry matter components (leaves, stems, coarse and fine roots) and needle chlorophyll concentrations are not yet complete.

Results. After 16 weeks, no symptoms of foliar damage consistent with the applied H_2O_2 treatments were observed. Similarly, no difference in CO_2 or H_2O exchange characteristics resulted from the treatments. The 16-week dark respiration and light-saturated photosynthesis data for 8 seedlings from each treatment are presented in Table 6. Although final analyses of height and diameter information are not complete, calculations of treatment means indicate little effect of the H_2O_2 exposures on shoot growth. The analysis of leaf biomass data (particularly the root biomass data), and chlorophyll concentrations must be completed before final conclusions can be made regarding the effects of "H_2O_2 fog" on spruce seedling growth.

Table 3.--Comparative photosynthetic capacity of foliage of red spruce sampled in the Smoky Mountains in June and September.

		June			September			
		Upper elevation	Lower elevation		Upper elevation	Lower elevation	Upper elevation	Lower elevation
		Photosynthetic rate[1]					PS:Rs[2]	
Saturation Ps	1 yr	3.09	4.24	1 yr	3.69	3.44	2.76	4.03
	SE	0.43a[3]	0.28b	SE	0.19a	0.27a	0.71a	0.44a
	N	11	11	N	15	16	8	4
	3 yr	2.53	2.94	Current	3.44	4.48	3.48	4.33
	SE	0.19a	0.34a	SE	0.28a	0.30b	0.65a	0.44a
	N	11	16	N	16	16	8	4
Low ration Ps (100-300ue)	1 yr	1.45	3.2					
	SE	0.48a	0.19b					
	N	8	8					
	3 yr	1.30	1.92					
	SE	0.32a	0.33a					
	N	8	7					

[1] Photosynthetic rates are relative values for a 3.6 cm shoot segment expressed as μmole CO_2 m^{-2} sec^{-1} based on an assumed needle surface area of 10 cm^2. Needle wt on a 3.6 cm segment averaged approximately 0.11 g for both sites.

[2] Ratio of dark respiration to light saturated photosynthesis.

[3] Values within an age class and sample date followed by different letters are significantly different at the 5% level.

Table 4.--Chlorophyll A (Chl. A), B (Chl. B), total chlorophyll, carotenoids (Caroten.), and A/B ratios in current, 1 year and 3 year old foliage of red spruce growing at high and low elevations. Each value represents the mean of 4 seedlings. Values for a variable, within a tissue type followed by different letters are significantly different at the 1% (a, b), 5% (s,t), or 10% (x,y) level.

	Tissue age					
	Current		1 yr old		3 yr old	
	Upper	Lower	Upper	Lower	Upper	Lower
Chl. A	2.55	3.43	3.65	4.42	3.98	4.72
(mg/gDW)	a	b	s	t	ns	ns
Chl. B	1.27	1.75	1.91	2.47	2.15	2.47
(mg/gDW)	a	b	s	t	s	t
Tot. A + B	3.83	5.18	5.56	6.88	6.13	7.46
(mg/gDW)	a	b	s	t	x	6
Caroten.	0.49	0.59	0.70	0.81	0.80	0.89
(mg/gDW)	a	b	x	y	ns	ns
Ratio A/B	2.01	1.97	1.92	1.79	1.85	1.73
	ns	ns	a	b	a	b

Table 5.--Relative water content (RWC) at turgor loss point (tlp), turgor loss point osmotic potential, and saturated osmotic potential (Sat) in red spruce foliage. The July 16 sample represents current and 1 year old foliage combined; all others are current year tissue only. Each value represents the mean of five samples. Values within a date followed by different letters are significantly different at the 5% level (a, b) or the 10% level (x, y).

	Sample Dates							
	July 16		July 29		August 25		September 29	
	High	Low	High	Low	High	Low	High	Low
RWC at TLP	0.84 a	0.88 b	0.84 a	0.88 b	0.85 a	0.88 b	0.87 a	0.87 a
Osm. at TLP	-1.38 a	-1.29 b	-1.84 a	-1.51 b	-1.48 a	-1.34 a	-1.47 a	-1.48 a
Osm. at Sat.	-1.06 x	-0.94 y	-1.54 a	-1.19 b	-0.94 a	-0.95 a	-0.90 a	-0.97 a

Table 6.--Dark respiration and light saturated photosynthesis of *Picea rubens* Sarg. seedlings exposed to 0, 0.5, 2, and 8 mg/l H_2O_2 in acid fog ("mist") for 16 weeks.

Treatment (mg l^{-1})	Dark respiration[1] (μmol CO_2 m^{-2} s^{-1})	Light-saturated photosynthesis[2] (μmol CO_2 m^{-2} s^{-1})
0	-0.77 ± 0.31[3]	3.24 ± 0.64
0.5	-0.78 ± 0.30	3.50 ± 0.67
2	-0.68 ± 0.24	3.30 ± 0.85
8	-0.68 ± 0.24	3.16 ± 0.70

[1] Instantaneous measurements taken in the dark following photosynthetic measurements.

[2] Measurements include photosynthetic rates measured at 900 to 1525 μmol quanta m^{-2} s^{-1}.

[3] Mean ± standard deviation of 8 seedlings per treatment.

Nitrogen Metabolism

Objective. To examine the potential role of foliar absorbed nitrogen as a factor in the physiology of red spruce.

Approach. This researh has proceeded in three phases: (1) determination of the extend to which nitrate reductase (NR) activity (Gebauer et al. 1984) can be induced and determination of optimal procedures for its detection in initial exploratory studies that have used uptake of nitrate through the stem as N source; (2) testing of atmospheric induction of NR using the gas NO_2 at 95 nl l^{-1} as the source in controlled laboratory exposures; and (3) a survey of NR activity from foliage collected in the field.

Results. The standard protocol for the NR assay has been modified for red spruce needles. Incubation temperatures above 30°C (as are commonly used with other species) were found to inhibit activity, and much better results are obtained with room-temperature incubations. We have also determined that the optimum propanol concentration in the incubation medium is 0.5%, and concentrations above 1% are inhibitory. The optimum pH for the assay is pH 8. Maintenance of cut shoots in 5 mM KNO_3 for several days increases NR activity over the very low levels found in intact seedlings, which indicates that NR can be induced in spruce foliage. Preliminary experiments have also suggested that 95 nl l^{-1} NO_2 induces NR within 1 day in red spruce seedlings. Also, NR activity of red spruce needles collected from the GSMNP on September 24, 1987, was approximately 50% higher at the high-elevation site than at the lower-elevation site, and needles from the high-elevation site also exhibited a greater capacity for NR induction after exposure to NO_2.

Trace Metal Toxicity

Objectives. (1) To develop rapid screening techniques for examining the toxicity to red spruce of individual and combined trace metals. (2) To determine individual and combined toxicities of aluminum and manganese to growth of red spruce roots in the presence of varying calcium supply ratios.

Approach. Controlled laboratory studies are being conducted to develop optimum substrate type, nutrient solution pH, and solution ionic strength for evaluation of growth responses of red spruce seedlings to aluminum and manganese in the presence of varying relative ratios of calcium. Toxicity testing consists of evaluation of growth of shoots and roots and foliar levels of nutrients of 25 seedlings subsets following an 8 week growth period in six levels of Al (0, 0.1, 1, 2.0, 5 and 10 ppm) 6 levels of manganese (0, 1.0, 5.0, 10.0, 30 and 60 ppm) at Ca:Al ratios (0.25, 0.5, and 1.0) that reflect those currently being measured at the EPRI sponsored IFS site near our lower elevation study site.

Results. None to report at this time. Media and substrate tests have been completed and toxicity tests are in progress.

Discussion

This study represents an initial exploratory attempt to characterize spruce physiology at high elevations in the field. While a majority of the first year data are still being analyzed, the preliminary results suggest that spruce growth and physiology differ considerably between 1720 and 1935 m elevations at sites where growth of mature trees did not differ substantially in the past. Reduced growth now occurring at these northeastern facing sites is associated with reduced carbon assimilation capacity that appears to be a consequence of reduced foliar chlorophyll, reduced photosynthesis, altered leaf water status and increased respiration. The next critical step is to fully characterize the magnitude and seasonal kinetics of these differences with additional seasonal data and to formulate testable hypotheses regarding the role of natural and anthropogenic factors involved.

Acknowledgments

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Reactions of Norway Spruce to Air Pollution in Fumigation Experiments and in Damaged Forest Stands

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Abstract

With the given long-term exposures to various phytotoxic air pollutants, the major components of the present forest decline cannot only be determined by field studies. To countercheck the diagnosis by hypothesis testing, laboratory experiments under controlled and reproducible conditions must be added. Some significantly similar phenomenological, physiological and histological/cytological changes in both the spruce in fumigation experiments and the spruce trees in damaged forest stands support the thesis that it is mainly the combination of ozone and sulfur dioxide associated with NO_x *and acidic precipitation that must be regarded as a primary and major predisposing cause of forest decline. The damage pattern in the Black Forest seems more likely to be induced by ozone, that of the Fichtel Mountains by sulfur dioxide.*

The University of Essen Institute of Applied Botany, founded nearly ten years ago, has studied the effects of air pollution on forest trees for some six years. The exposure systems available are climatic chambers and greenhouses, as well as open-top chambers since 1987, with facilities that allow several gaseous air pollutants to be applied and measured. The results of experiments with spruce trees exposed to nearly realistic concentrations of sulphur dioxide, ozone and nitrogen dioxide, singly and in combination, are reported in the following. Some results of comparative geobiological investigations of damaged and undamaged forest stands in the Federal Republic of Germany are presented in addition.

In order to contribute eventually to the knowledge on the causes of recent forest damages and of the dose-response relationships, the effects exhibited in the fumigation experiments and in the field studies are measured and evaluated on a range of criteria. They consider visible injury symptoms, the growth of shoots and roots as well as physiological/biochemical and histological/cytological changes. The following report is introduced by the data of exposures used in the fumigation experiments selected (Table 1).

Effects on Growth and Appearance

In climatic chamber and greenhouse experiments the test trees exhibited a variety of visible symptoms of damage, depending on the kind of pollutants and the combinations of them, on their concentrations, on the exposure duration and on the nutrient supply of the plants.

In the course of a fumigation experiment carried out in the greenhouse for nearly two growing seasons (Table 1, Experiment 1), the one-year-old needles showed extended yellow banding within a few weeks of the second year of exposure to O_3 and O_3/SO_2, respectively. The current year needles showed chlorotic mottling no earlier than at the end of the second year and only after a combined exposure. Reference trees as well as those exposed to SO_2 alone remained free of similar symptoms.

In another greenhouse experiment (Experiment 2) only a few weeks of exposure to O_3/SO_2 were necessary to cause small chlorotic spots (chlorotic mottling) on current year needles. After wintering, drastic losses due to frost were recognized among the spruce trees exposed to O_3 and particularly to O_3/SO_2. Individuals exposed to SO_2 as well as reference trees exhibited no damage of that type.

In a climatic chamber experiment (Experiment 3) exposures to various combinations of O_3, SO_2, and NO_2 caused yellowing of the needles, running from the tip to the base in the course of the experiment. The upper surface was affected earlier and more severely than the lower surface. Combinations of all three pollutants caused more severe effects than O_3/NO_2, only slight damage was observed after exposure to SO_2/NO_2.

No or only slight growth reductions could be recognized in the course of the fumigation experiments that ran over only one growing season (Experiments 2 and 3). Exposure to O_3 or SO_2 over two growing seasons (Experiment 1) caused remarkably reduced production of the aboveground biomass as well as of the root. A combined fumigation reduced both needle and stem dry weight of the young shoots by 50 percent. Smaller weight reductions resulted from exposures to the single pollutants. Decreased dry weights of the older wood segments reflect the influence on the growth in thickness. Root growth was remarkably reduced compared to the degradation of the aboveground parts.

Physiological/Biochemical Changes

These outlined effects on the total organism manifested by growth reductions and visible injury symptoms are the consequences of various functional and structural changes that will be discussed in the following examples.

Table 1.--Exposure conditions

Experiment	Exposure system	Exposure duration	Concentration ($\mu g/m^3$)		
			O_3	SO_2	NO_2
1	Greenhouses	1st year: 22 weeks	8-16.00: 200 16-8.00: 100	100 continuously	---
		2nd year: 16 weeks	10-18.00: 160 18-10.00: 80	75 continuously	---
2a	Greenhouses	22 weeks	10-18.00: 240	75 continuously	---
2b	Greenhouses	22 weeks	10-18.00: 140 18-10.00: 50	75 continuously	---
3	Climatic chamber	26 weeks	8-16.00: 150 16-8.00: 50	75 continuously	75 continuously
4	Climatic chamber	12 weeks	6-20.00: 194 20-6.00: 0	292 continuously	---
5	Climatic chamber	20 weeks	6-20.00: 176 20-6.00: 0	258 continuously	---
6	Climatic chamber	year	9-17.00: 30,60,80 17-9.00: 0	50,100,200 continuously	---
7	Climatic chamber	year	9-17.00: 75 17-9.00: 0	100 continuously	---

Effects on Carbohydrate Budget

Photosynthesis and respiration. At the end of a six month's climatic chamber experiment (Experiment 3), net photosynthesis of needles of different age classes was measured as a function of light intensity (Fig. 1). Fumigation hardly affected net photosynthesis of current year needles. In contrast, one-year-old needles exhibited a strong reaction. The combination O_3/NO_2, resulting in a 37 percent reduction of the photosynthetic rate compared to the control, proved to be more effective than SO_2/NO_2. More than an additive effect was recognized after treatment with $O_3/SO_2/NO_2$, inhibiting maximum O_2-production by 73 percent. Reduction of photosynthetic rate was accompanied by decreased quantum yield and by a shift of the light compensation point to higher values. In the long term greenhouse experiment (Experiment 1) current year needles with slight visible symptoms exhibited only little decrease of apparent photosynthesis, the combination O_3/SO_2 being most effective (Fig. 2A). While air pollution stress reduced photosynthesis, dark respiration was stimulated (Fig. 2B). O_3, singly and in combination with SO_2, proved to be particularly effective, causing a stimulation of respiration up to 40 percent compared to the control. One-year-old needles, which especially after treatment with O_3/SO_2 showed extensive chlorosis, exhibited a strong depression of photosynthetic capacity. Combined pollutants caused a 50 percent reduction, whereas SO_2 and O_3 alone had smaller effects. In contrast to the reaction of current year needles, respiration of one-year-old needles was less affected. O_2-uptake in the dark increased significantly only after fumigation with O_3 as a single component.

In the geobiological studies in the Fichtel Mountains and in the Black Forest the slightly damaged reference trees exhibited clearly higher apparent photosynthetic rates than the test trees with medium to severe damage (Fig. 3). Even if the photosynthetic rates of the reference trees decreased with increasing needle age, they remained on a high level if compared to those of the damaged trees. Because the respiration rates of the reference trees decreased as well with increasing age of the needles, all needle ages exhibited positive metabolic rates (Fig. 4). Unlike the reference trees, the photosynthetic rates of the damaged spruce trees decreased drastically with increasing needle age. Respiration, however, was greatly stimulated. Carbohydrate supply of a damaged tree in the Black Forest that exhibited only 3 needle ages was mainly confined to the positive photosynthetic rates of only two needle ages.

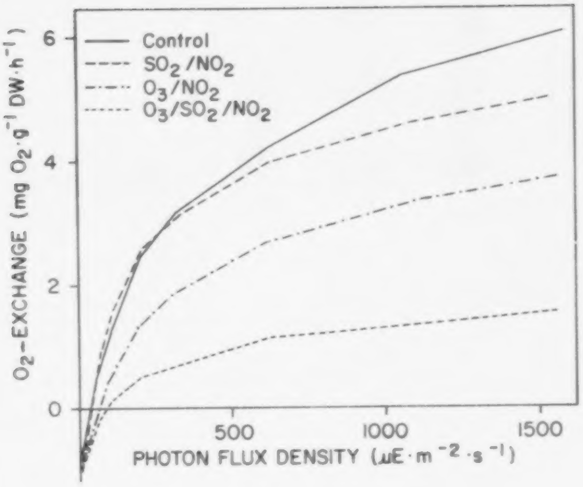

Figure 1.--Light response curves of one-year-old needles after exposure to O_3/NO_2, SO_2/NO_2, and $O_3/SO_2/NO_2$.

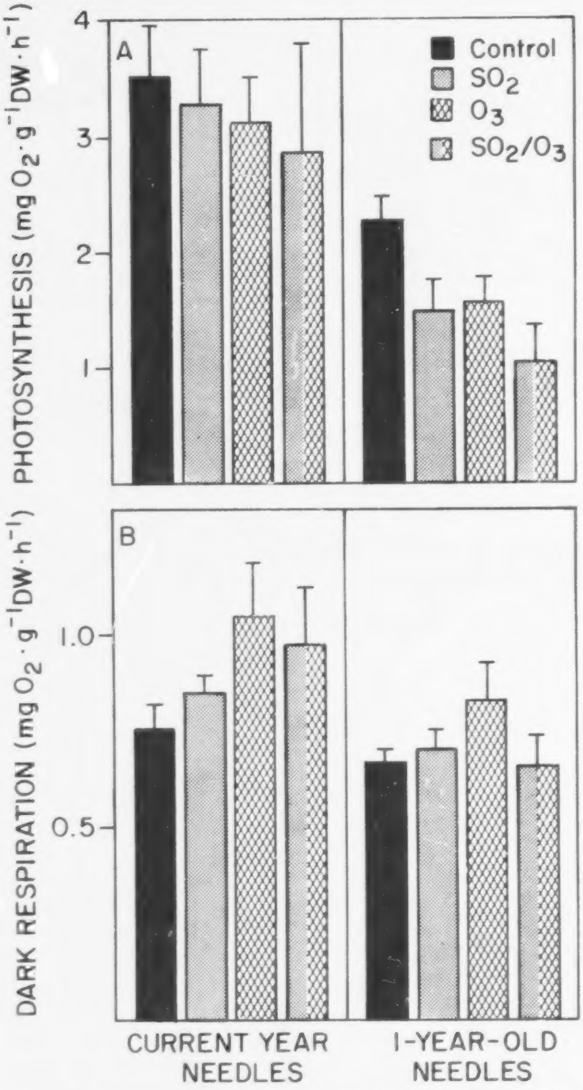

Figure 2.--Net photosynthesis (A) and dark respiration (B) of current and one-year-old needles after fumigation with O_3 and SO_2, singly and in combination.

Starch and sugar budgets. Starch contents of needles of two age classes treated with O_3 and SO_2, singly and in combination (Experiment 1), differed significantly, depending on the type of pollution. Fumigation with SO_2 alone had no influence on the starch concentration. Treatment with O_3 caused a marked accumulation of starch, particularly in one-year-old needles (Fig. 5). An even stronger increase was observed in needles of the same age after exposure to O_3/SO_2. Current year needles fumigated with combined pollutants showed no effect. In contrast to needles, starch levels in roots of fumigated plants were strongly reduced. Again, the combination O_3/SO_2 was most effective, resulting in a 67 percent reduction compared to the control. O_3 and SO_2 alone decreased starch contents by 62 and 58 percent, respectively. Elevated starch levels in needles and lowered concentrations in roots indicate that partitioning of assimilates is affected.

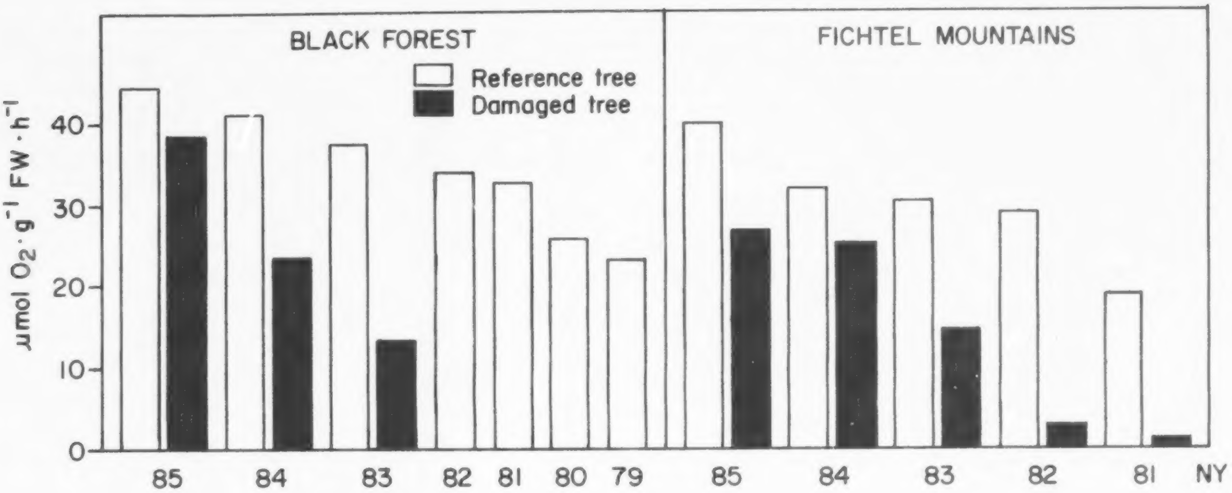

Figure 3.--Apparent photosynthesis of the reference trees and the severely damaged spruces in the Black Forest and the Fichtel Mountains.

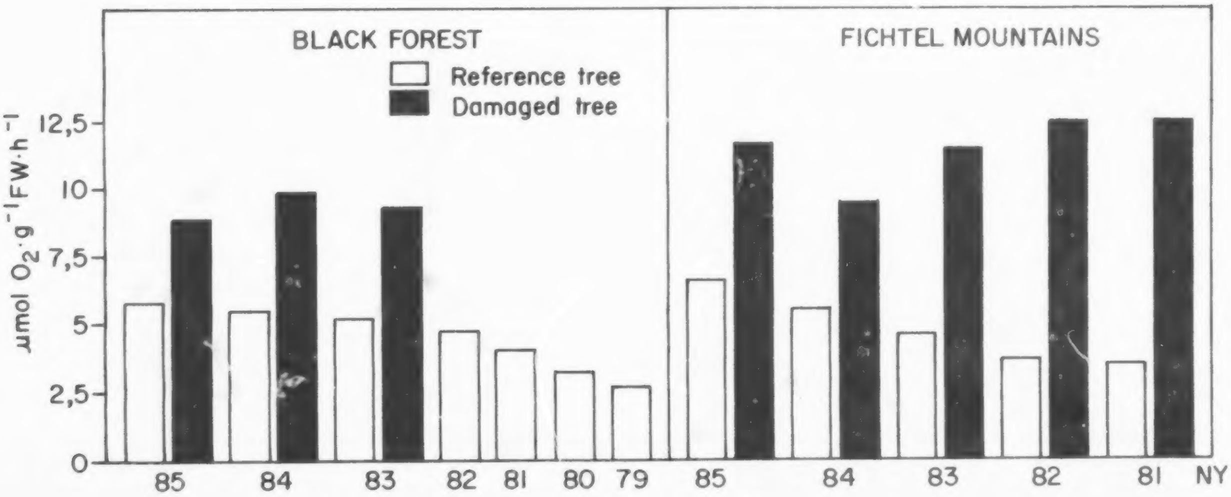

Figure 4.--Respiration of the reference trees and the severely damaged spruces in the Black Forest and the Fichtel Mountains.

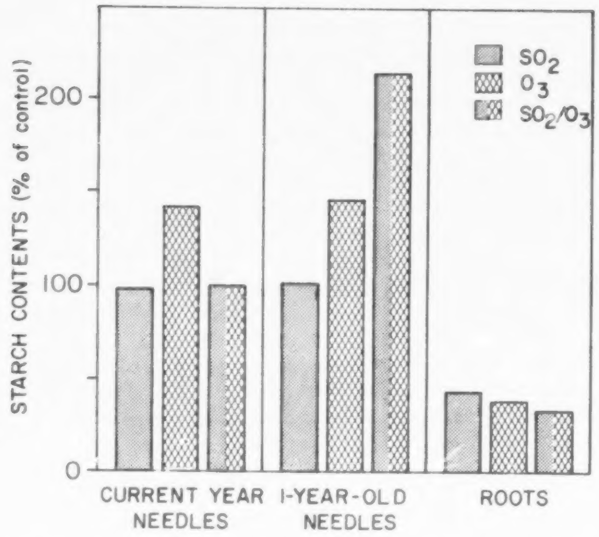

Figure 5.--Effects of O_3 and SO_2, singly and in combination, on starch in needles and roots.

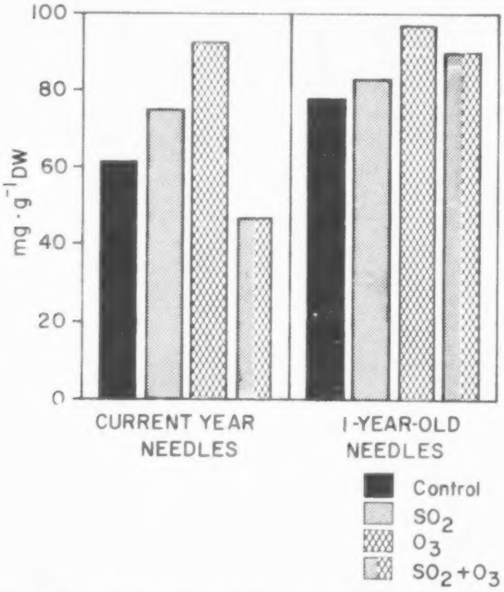

Figure 6.--Effects of O_3 and SO_2, singly and in combination, on sugar contents in current and one-year-old needles.

In the course of another fumigation test (Experiment 4) increased total sugar contents were detected in both new and old shoots of the fumigated individuals (Fig. 6). The plants exposed to O_3 showed the highest rates of increase. The analysis of the single sugar components in the needles of reference and damaged trees from the Fichtel Mountains and Black Forest revealed mainly seasonal, but only few pollution-induced variations. For example, raffinose could only be detected in December, with the values of the reference trees being 10 to 20 percent higher than those of the damaged trees. While fructose showed some minor seasonal changes, glucose levels were high at the end of the sprouting period, in June, and in December as well, but low in September. Sucrose increased continuously over the year to a December maximum from only small amounts at the end of the sprouting period. In comparison to unaffected trees, damaged spruce trees exhibited lower sugar contents in December but higher levels in July and September. In summer, at the time of the highest physiological activity, a sugar congestion could be recognized in the damaged spruce trees in spite of their limited photosynthetic capacities.

The starch content was at its maximum at the beginning and in one needle age class at the end of the sprouting period, i.e. in May and June (Fig. 7), whereas in September only a low level and in December no starch was measured. Sugar contents increased towards winter, those of starch decreased. Comparative studies of slightly and severely damaged spruce trees revealed some remarkable differences in starch accumulation which were more distinct in the Black Forest than in the Fichtel Mountains. The greatest differences were in May. In comparison to the reference trees, the average starch content of four needle ages from the Fichtel Mountains was reduced by up to 68 percent. Therefore, it can be stated that severely damaged spruce trees had remarkably fewer reserves to produce new sprouts than slightly damaged individuals. Contrarily, but corresponding to the results of the greenhouse experiment (Experiment 1), in September the starch contents were higher in damaged than in reference trees.

Water Economy

In the course of investigating the carbohydrate metabolism (Starch and sugar budgets section) it has already been pointed out that increased sugar contents (Experiment 4) were observed in SO_2 and O_3 climatic chamber experiments despite decreased photosynthetic potentials (Fig. 8). The increase in osmotic potential was caused by an increase of osmotic particles. Because the water potentials of the xylem of fumigated spruce trees were reduced in comparison to those of the reference trees, it must be assumed that SO_2 and O_3 exposed test plants exhibited increased pressure potential and contained more water than the untreated reference trees.

Raised water contents in the fumigated trees could also be shown by measuring the fresh/dry weight relations. But in spite of increased water content in these fumigated plants their transpiration rates were reduced. The causes are thought to be limited regulation of the stomata and less available water to serve as a carrier and to promote chemical reactions because of its stronger linkages to sugars and ions.

Field tests with damaged trees brought similar results. In midsummer, increased osmotic potential could be observed in severely damaged trees due to raised sugar contents. Measurements of the fresh/dry weight relations confirmed the raised water contents in the needles of damaged spruce trees as well. Because both water potential and transpiration have to undergo remarkable diurnal changes under field conditions, the reference and damaged Fichtel Mountain spruce trees exemplify the diurnal courses of these two parameters (Fig. 9). Even if the reference tree achieved remarkably higher maximum rates of both water potential and transpiration than the damaged tree at noon stress time, the fact that both

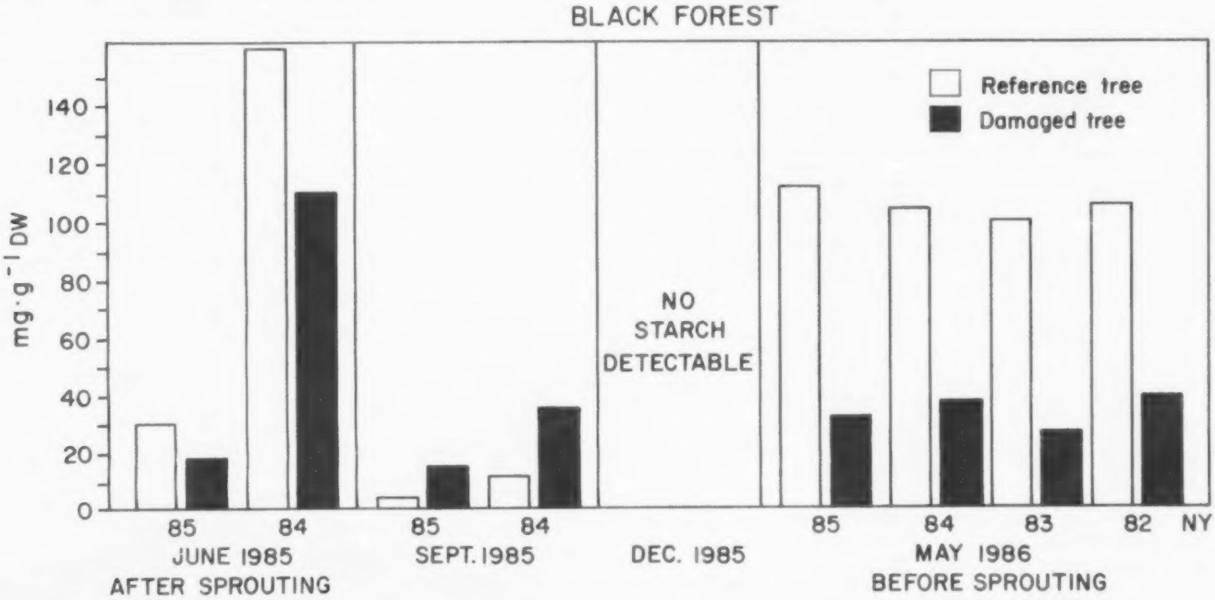

Figure 7.--Starch contents of the reference tree and the severely damaged spruce in the Black Forest.

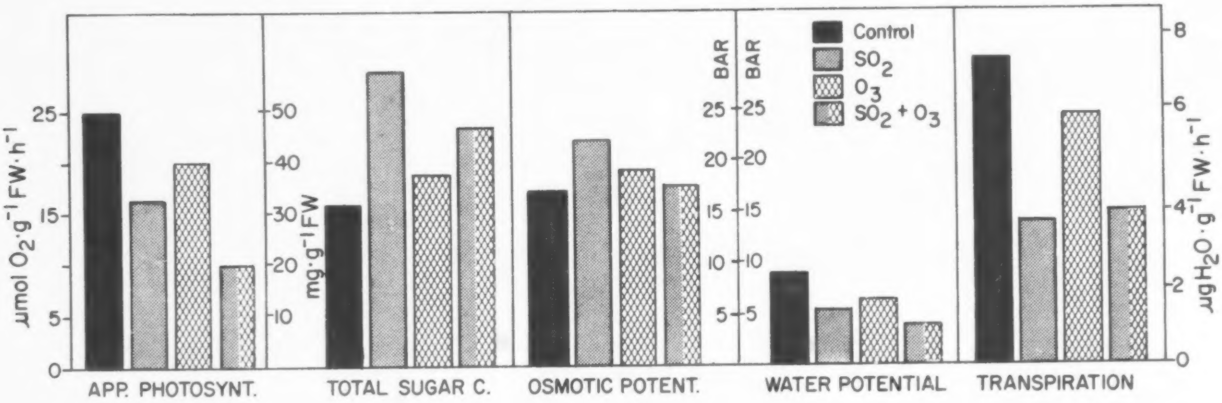

Figure 8.--Apparent photosynthesis, total sugar content and water budget of spruce clones after exposure to sulfur dioxide and ozone, singly and in combination.

spruce trees exhibited similar diurnal courses of the parameters shows that the regulation of the water economy of the damaged tree may be restricted but is still effective.

Investigations of proline content as a mainly non-specific indicator of water stress (see Stress indicators section) exhibited significantly increased concentrations in the needles of fumigated spruce trees as well as those in damaged forest stands. Despite higher water content, the severely damaged trees quite obviously were more severely affected by water stress than the slightly damaged trees so that they may be particularly endangered in the course of long lasting dry periods.

Mineral Budgets

Mineral contents. Exposure to O_3 and SO_2, singly and in combination, over two growing seasons (Experiment 1) caused a significant increase of Ca and K concentrations in the current year needles. The Mg contents, however, changed only slightly. One-year-old needles fumigated over two growing seasons exhibited increased potassium concentrations, the Mg and Ca contents, however, only increased after exposure to SO_2 alone.

Much higher changes in mineral budgets were caused by fumigation experiments running over one growing season. After exposure to O_3/SO_2 (Experiment 2a), the mineral contents of the current year needles were significantly increased (Fig. 10). The reactions of the plants to pollution stress varied depending on their nutrient supply. If cultivated in sand with a sufficient Mg and Ca supply, the mineral contents of fumigated spruce trees were elevated by 10 to 34 percent. If, however, cultivated in sand with a Mg and Ca deficiency or in soil, these contents were raised by 40 to 70 percent, when compared to non-fumigated controls under the same nutrient conditions.

Leaching

Minerals. If exposed to O_3 and SO_2 (Experiment 1) the leaching of nutrients was raised but depended on the nutrient supply. The leaching of Mg, Ca and K out of one-year-old needles of sand grown plants with sufficient nutrient supply was similar to that of the control trees, whereas exposure to SO_2 caused a 86 percent increase of Mg leaching and a 42 percent increase of Ca leaching from trees without Mg and Ca fertilization (Fig. 11). Exposure to ozone and O_3/SO_2 had only slight effects. As the figure shows, the Mg and Ca losses were increased remarkably when the deionized water was acidified, whereas the K leaching was not influenced by pH.

Repeated measurements of Mg, Ca and K leaching under O_3/SO_2 conditions (Experiment 2b) proved that the reaction of the spruce trees was influenced by nutrient supply. After four weeks of exposure (June 1985), sufficiently nourished plants exhibited unchanged susceptibility to leaching, whereas Mg and Ca

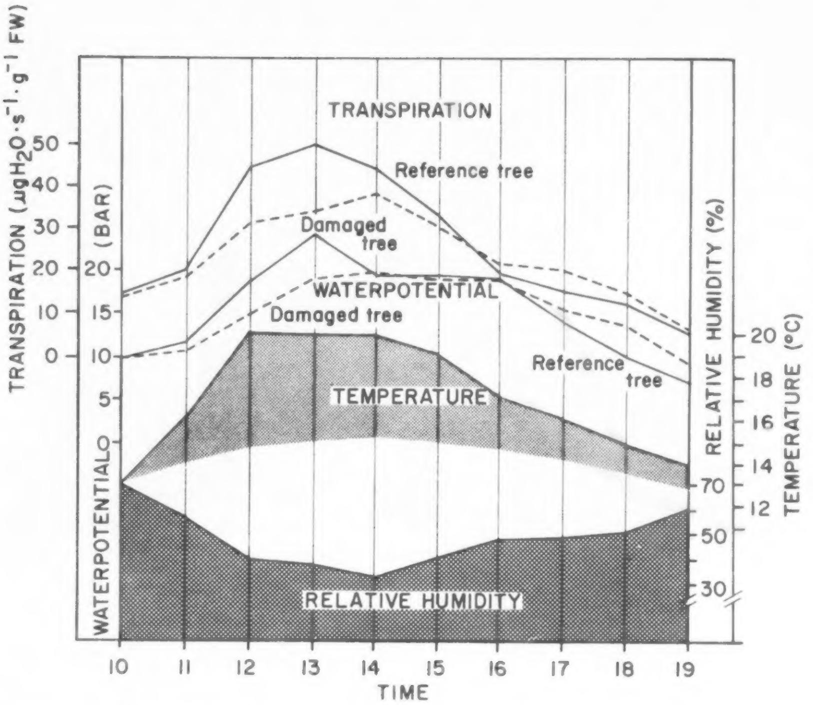

Figure 9.--Diurnal water budget rates of the reference tree and the severely damaged tree in the Fichtel Mountains.

deficiencies increased this susceptibility by up to 50 percent in comparison to the reference trees (Fig. 12). At the end of the growing season (September 1985) plants sufficiently supplied with Mg and Ca exhibited an increased susceptibility as well due to pollutant stress. Leaching from fumigated and insufficiently nourished plants did not further increase. When a third measurement was made after wintering without air pollution stress both fumigated trees and reference trees showed similarly increased leachability of Mg and Ca. After an exposure to O_3/SO_2, however, leaching of K is increased remarkably in comparison to insignificant changes in the reference trees.

Analyzing the calcium and magnesium concentrations of the needles of both the reference trees and the damaged trees, we found that:

-the Fichtel Mountain trees showed higher mineral contents,
-the contents varied markedly in needles of different ages,
-high seasonal changes in concentrations are evident, and
-the needles of the damaged trees had lower overall concentrations.

The trees of the two sites varied distinctly in the supply of calcium. The calcium rates of the Fichtel Mountain spruces were approximately twice as high as those of the Black Forest trees. At both sites the calcium rates of the reference trees and of the damaged trees increased with the age of the needles. Unlike this the magnesium concentrations present a controversial picture: in the Black Forest samples they decreased markedly with increasing ages of the needles, whereas the Fichtel Mountain trees showed nothing but a slight decreasing tendency. With some exceptions, the lowest concentrations were detected in December, the decrease being more distinct in the magnesium contents.

Comparing the damaged trees and the reference trees, particularly the damaged Black Forest samples exhibited lower concentrations. Again, the relative difference in magnesium was greater than that of calcium.

Just as the contents of the needles, the leaching rates depend to a high degree on the site, the age of the needles, and the season.

If the full range of values of both years is compared, it can be recognized that higher Ca amounts were leached out of the Black Forest samples than out of the Fichtel Mountain trees. Both the rates relative to the needle content, and the absolute rates were higher. With significantly lower Ca contents of the needles, the concentrations washed out of the Black Forest samples were higher than those washed out of the Fichtel Mountain trees. The absolute amounts of magnesium washed out were approximately the same at both sites. Most of the damaged trees exhibited both higher absolute and relative leaching rates than the reference tree, with the exception of the Black Forest reference tree with

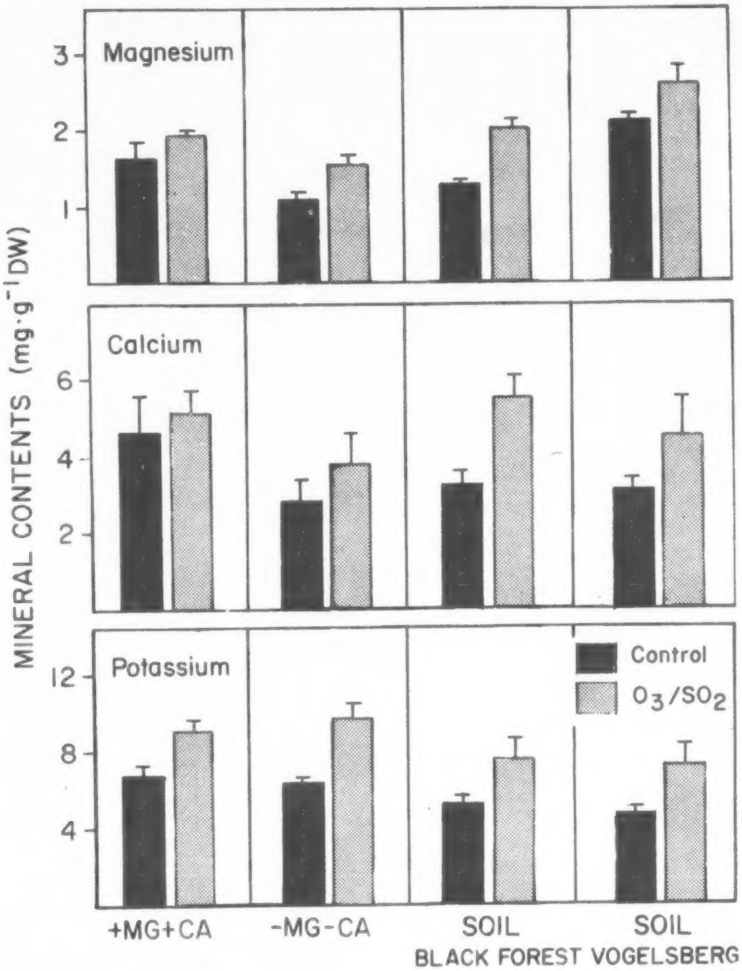

Figure 10.--Impact of O_3/SO_2 on the mineral contents of current year needles of spruce cultivated on sand and different soils.

significantly higher Ca leaching rates. In December no calcium and magnesium concentrations could be detected in the leaching water.

Organic compounds. In a preliminary study of the leaching of organic substances, severely damaged spruce trees from the Egge Mountains with only four needle sets and discoloration of the needles were compared with relatively unaffected Sauerland trees. The results are as follows: Carbohydrates. - The three youngest needle ages of the severely damaged trees exhibited higher concentrations of the soluble carbohydrates fructose, glucose and sucrose as well as higher leaching rates than the undamaged trees. If the acidity of the leaching water is increased to pH 3.0, the concentration of carbohydrates is higher than with an acidity as low as pH 5.6. In the twigs of the lower whorls concentrations of soluble carbohydrates and relative leaching rates are higher than in the upper whorls. If compared to the needle contents, glucose is the most leached carbohydrate, whether pH is at 3.0 or at 5.6.

Lipid Contents

In the course of the climatic chamber experiment (Experiment 5) the highest contents of phospho- and galactolipids and, consequently, the highest contents of total lipids were measured in the needles of fumigated spruce trees (Fig. 13).

Generally, the galactolipids were the highest proportion of the total lipids. After fumigation, the phospholipids showed a

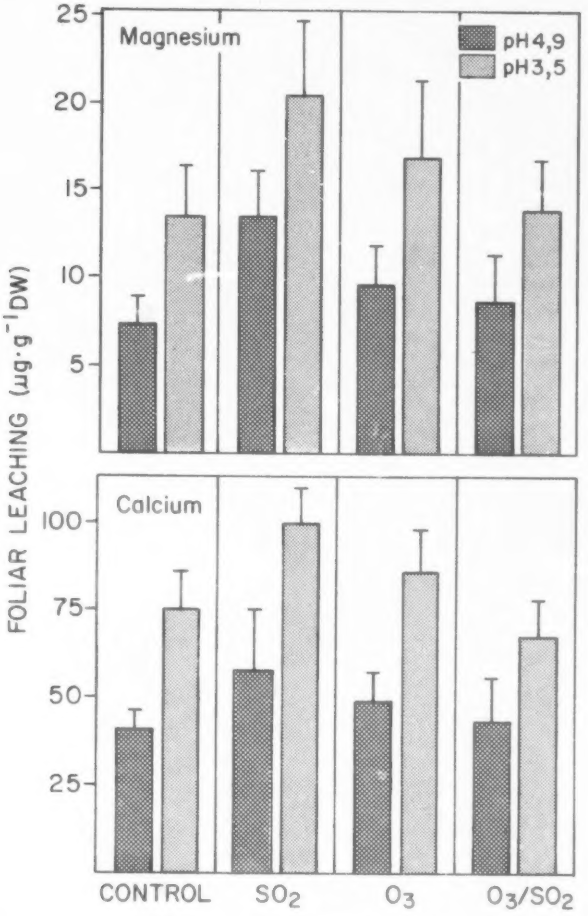

Figure 11.--Mineral leaching of one-year-old needles after fumigation with O_3 and SO_2 singly and in combination.

relatively higher rate of increase. Similar results, i.e. raised contents in the damaged trees, could be recognized in the course of the field tests, an indication of possible changes of the permeability of biomembranes.

Stress Indicators

To characterize the pollution-induced stress situation, proline levels (see Water Economy Section) as well as peroxidase activity and ethylene production were measured. These generally non-specific indicators were increased in all trees fumigated in the climatic chamber (Experiment 5). The highest peroxidase activity was observed after SO_2 exposure, the highest ethylene content after O_3 exposure. Combined fumigations caused antagonistic reactions of both parameters.

Corresponding to these results, raised ethylene levels and peroxidase activity were exhibited by the needles of severely damaged Fichtel Mountain and Black Forest trees (Fig. 14, 15). It must be pointed out that peroxidase activity was particularly high in the needles sampled in December 1985. The 1984 needles of the damaged trees sampled in the Fichtel Mountains and the Black Forest after a snow and frost snap showed peroxidase activity that was several times higher than that of the reference trees. In spite of "winter rest," but very likely due to the coincidence of pollution and frost stress, the highest increase of activity was observed in the needles of the one-year-old twigs.

Histological/Cytological Changes

Changes of the Cuticular Waxes

The eroding effects on the epicuticular waxes of the stomata of climatic chamber, Fichtel Mountain and Black Forest spruce needles were investigated with SEM. In climatic chamber

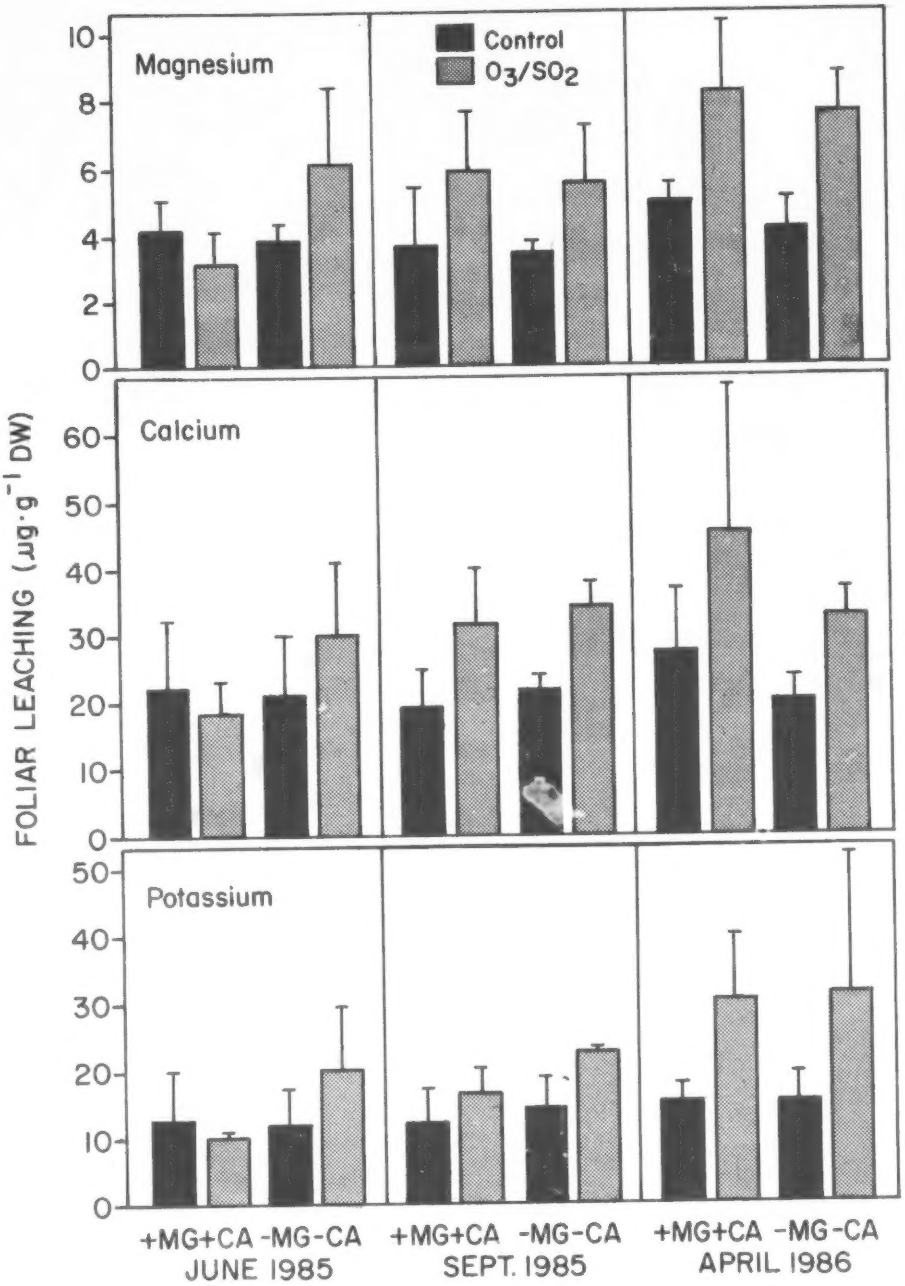

Figure 12.--Effects of mineral nutrition and fumigation with O_3/SO_2 on mineral leaching of current year needles.

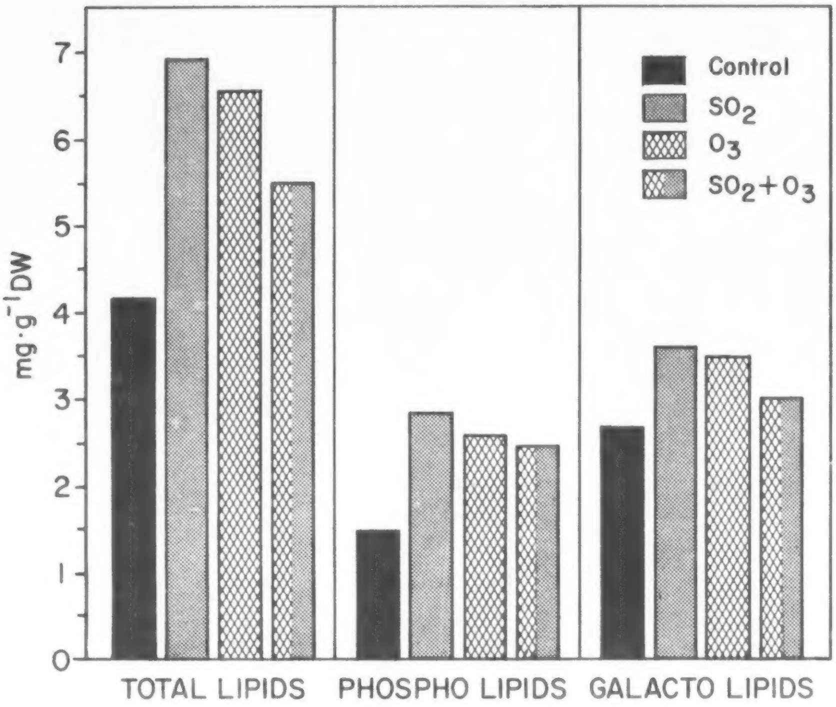

Figure 13.--Total, phospho- and galacto-lipid contents of spruce clones after exposure to sulfur dioxide and ozone, singly and in combination.

experiments (Experiment 6 and 7) young reference needles presented a relatively dense 'network' with wax fibrils distributed all over the surface and particularly in the stomata area (Fig. 16a, b). In older needles, these thread-shaped structures become shorter and tend to clump. Young stomata are covered with wax fibrils as well, but these are longer and extend deeply into the auricles of the stomata. These wax threads remain well preserved in older needles as well.

Fumigations with SO_2 and O_3, singly and in combination, changed the cuticular waxes. The eroding effect of the gas could clearly be seen when the wax covers of the reference needles of different ages were compared with the corresponding trees exposed to SO_2. After a 1-year-exposure, the wax threads of the stomata were mainly destroyed. The threads over the stomata were stuck together, partly covered the stomata like plates or sank into them (Fig. 16e, f). Needles from the mainly SO_2 stressed Fichtel Mountain trees exhibited similar destruction of the cuticular waxes.

Needles experimentally exposed to O_3 showed minor damages (Fig. 16c, d). The majority of the wax threads remained, with only some sticking in the stomata area. This corresponded to the reaction of the epicuticular waxes of spruce needles from the severely ozone stressed Black Forest.

Particular damage of the epicuticular waxes was caused by combined fumigations. The waxes can be completely destroyed, thus plugging the stomata or leaving them unprotected (Fig. 16g, h). The amount of amorphous epicuticular wax was clearly raised.

Changes of the Mesophyll Tissue

The quantitative approach to the histological analyses of spruce needles from climatic chamber experiments (Experiment 4) revealed differences in the effects of sulfur dioxide and ozone. Compared to the control trees an enlarged intercellular area of the primary needles (Fig. 17A) could be recognized after O_3 exposure, associated with an enlarged internal surface and consequently a raised internal/external surface ratio. Exposures to SO_2 caused the opposite responses. Both the intercellular system

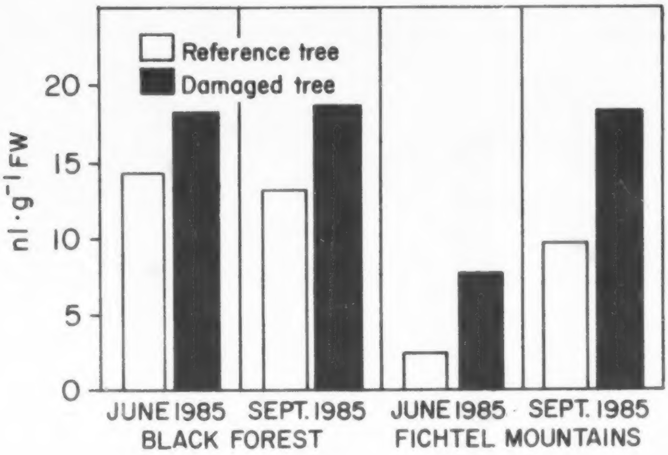

Figure 14.--Ethylene production of the reference trees and the severely damaged spruces in the Black Forest and the Fichtel Mountains.

and the internal surface were reduced, and the internal/external surface ratio decreased. Combined exposures to O_3 and SO_2 caused no significant changes of the relative intercellular area, allowing the deduction that opposing effects neutralize each other. The internal/external ratio, however, was increased, corresponding to the value after O_3 exposure. Comparing these results to those of the geobiological studies (Fig. 17B), the 1- and 2-year-old needles of the damaged Black Forest spruce tree exhibit the full range of characteristic responses to O_3. Both the intercellular system and the internal surface were enlarged and the internal/external surface ratio was increased. In the Fichtel Mountains, however, the opposite results were observed. With a slight decrease of the intercellular area both the internal surface and consequently the internal/external surface ratio are significantly reduced.

Changes of the Central Cylinder

Changes of the central cylinder as they can be observed in other damaged forest stands are exemplified by comparing 1-year-old needles of a slightly damaged reference tree and of a severely damaged Fichtel Mountain spruce tree (Table 2). The xylem as well as the intact phloem of the needles of the damaged trees were slightly reduced both absolutely and relative to the central cylinder, whereas the area of collapsed phloem was slightly extended. There was, however, a significant difference in the sizes of the cambium of the needles of the reference and of the damaged tree. That of the damaged needles was reduced by more than 50 percent. The spaces of the Strasburger cells and of the sclerenchyma, however, were significantly extended in the damaged needles.

Because the cambium of the damaged tree needles is significantly reduced, a reduced production of xylem and phloem elements and consequently disturbances of the water economy and of the transport of assimilates are to be expected in the second growing season. The enlargement of the area covered by Strasburger cells is mainly due to hypertrophic reactions of some cells. The swelling of these cells at the sides of the phloem, that transport the assimilates from the mesophyll to the phloem, may indicate congestion of assimilate. The raised sugar content, the raised osmotic potential as well as the increased water absorption may have caused the increase of the cellular volumes. The extension of the sclerenchyma in the needles of the damaged tree indicates congestion of carbohydrates and disturbances in partitioning.

Ultrastructural Changes of the Cellular Organelles

Ultrastructural analyses revealed a wide-ranging disintegration of chloroplasts from damaged Black Forest trees. If compared to the reference tree the grana were reduced in number and wider distributed. The granathylakoids tended to dilation. In the stroma, the electron translucent plastoglobules increased in both number and size, compared to those in the reference series chloroplasts. The chloroplast changes in the needles of the damaged Fichtel Mountain tree corresponded widely to the Black Forest symptoms of damage.

Starch congestion was observed in the cells of the needles sampled in summer (Fig. 18, see Starch and sugar budgets section). The

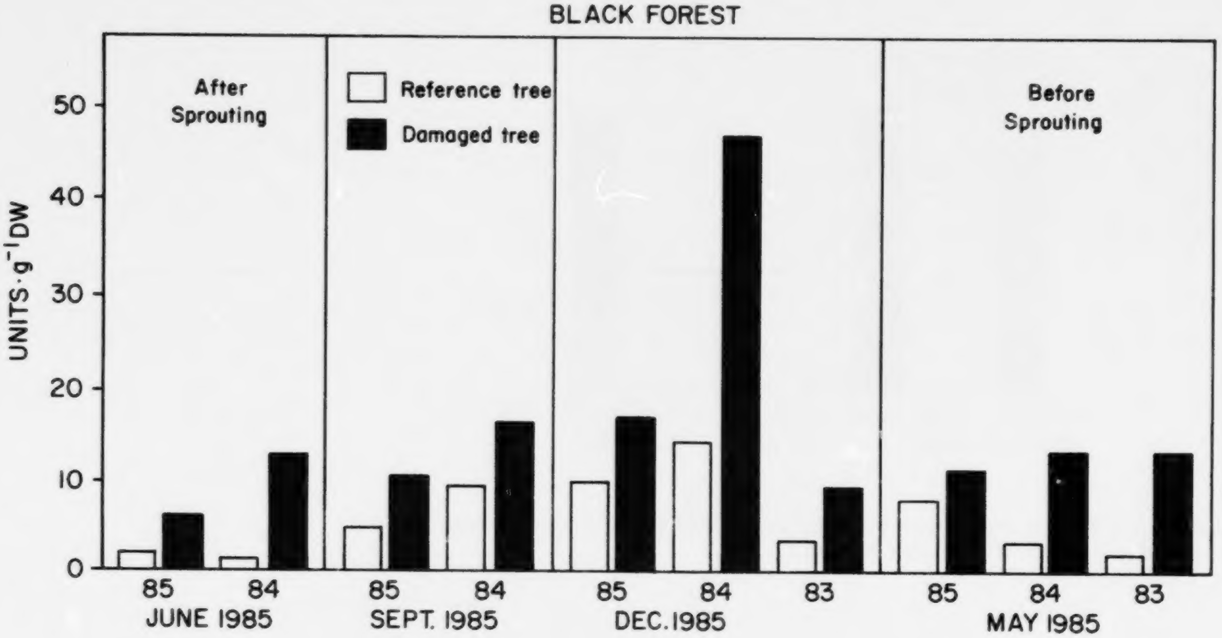

Figure 15.--Peroxidase activity in needles of the reference tree and the severely damaged spruce in the Black Forest.

vacuoles are sometimes densely filled with tannin corpuscles. Large amounts of tannin-filled vesicles can be found in the cytoplasm particularly next to the vacuole.

Table 2.--Changes of the central cylinder in one-year-old needles of the reference tree and the severely damaged spruce in the Fichtel Mountains

Item	Reference tree		Damaged tree	
	μm^2	% of Cc	μm^2	% of Cc
Central cylinder (Cc)	53199 ± 1457	100	48839 ± 3807	100
Xylem	2060 ± 67	3,87	1704 ± 322	3,49
Phloem intact	1169 ± 97	2,20	927 ± 133	1,90
Phloem collapsed	483 ± 58	0,91	510 ± 80	1,04
Cambium	1623 ± 155	3,05	675 ± 266	1,38
Sclerenchyma	3944 ± 464	7,41	5903 ± 2375	12,09
Strasburger cells	1281 ± 136	2,41	1717 ± 216	3,52

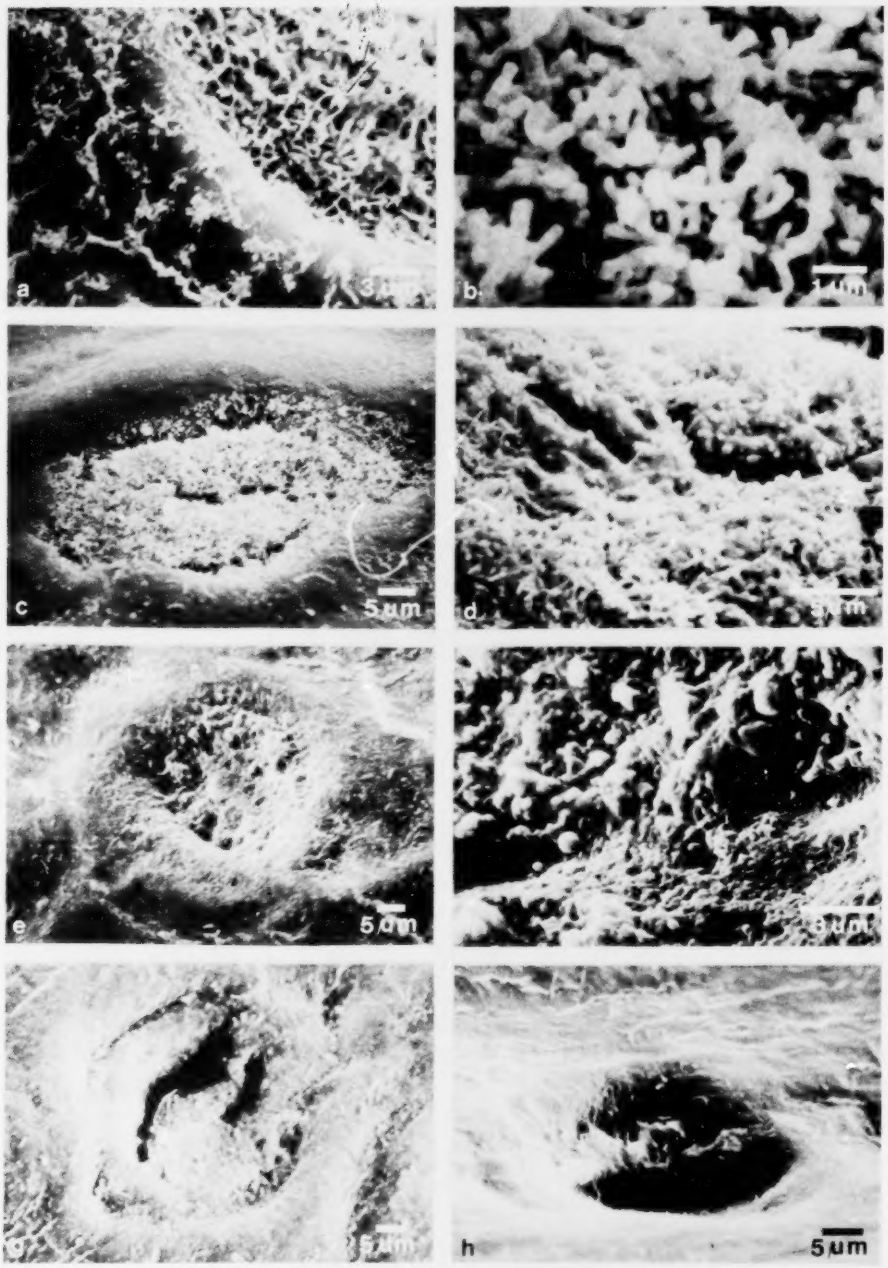

Figure 16a-h.--Electronmicrographs of needle surfaces of ***Picea abies*** in climatic chamber experiments: a) The epicuticular wax occurs around and in the stoma (control), b) Fine filaments of wax covering the stoma (control), c) Erosion of epicuticular wax around the stoma (O_3), d) Clusters of wax filaments (O_3), e) Fusion of wax filaments (SO_2), f) Partial destruction of the wax (SO_2), g) Destruction of the covering wax ($SO_2 + O_3$), and h) Complete degradation of the structural wax ($SO_2 + O_3$).

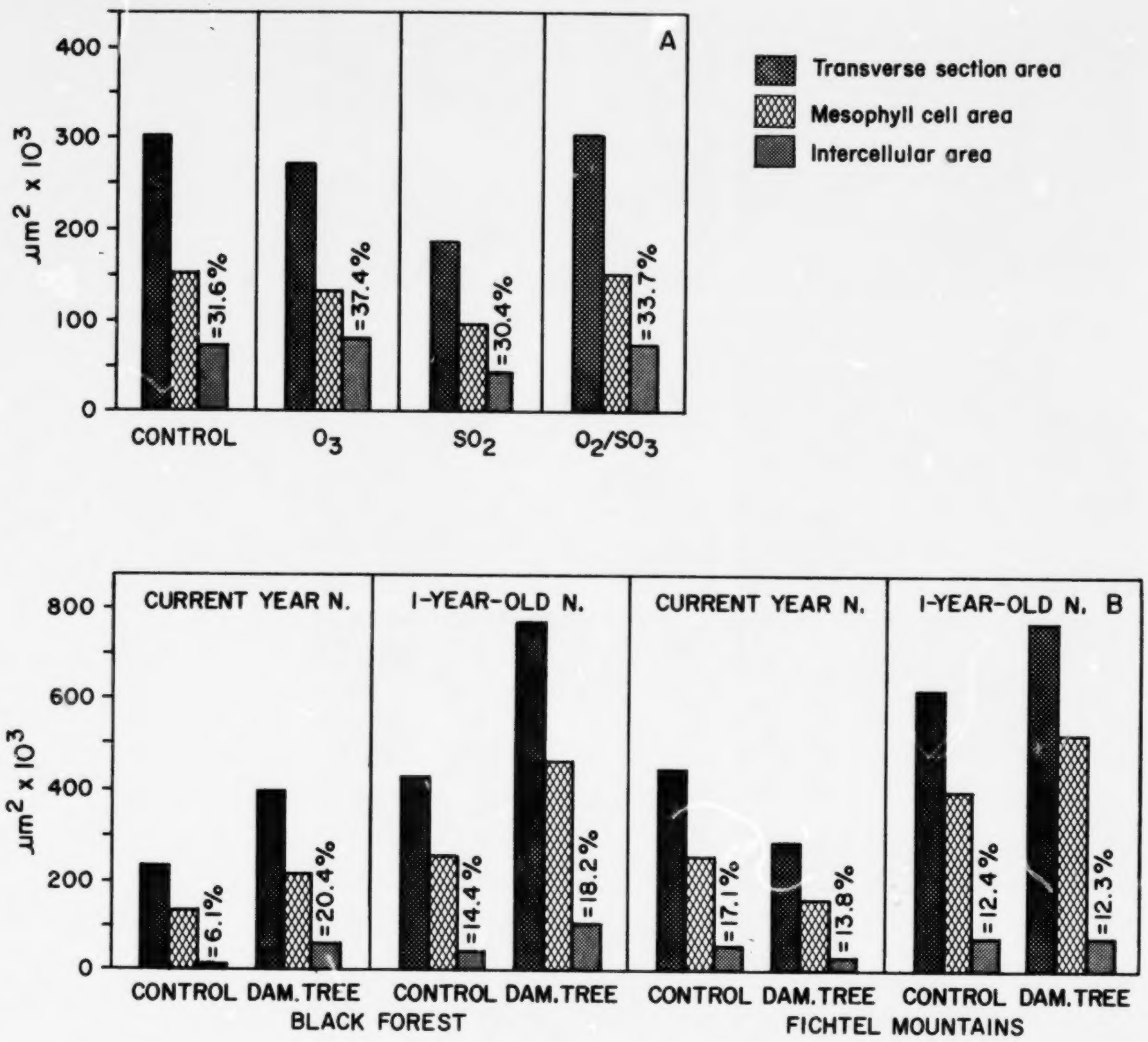

Figure 17.--(A) Results of histological studies on current year spruce needles after exposure to O_3 and SO_2, singly and in combination; (B) results of histological studies on current and one-year-old needles of Black Forest and Fichtel Mountain spruce trees. Effects on transverse section area, mesophyll cell area and intercellular area; the intercellular area values are given as absolute figures and as percentages of the mesophyll area.

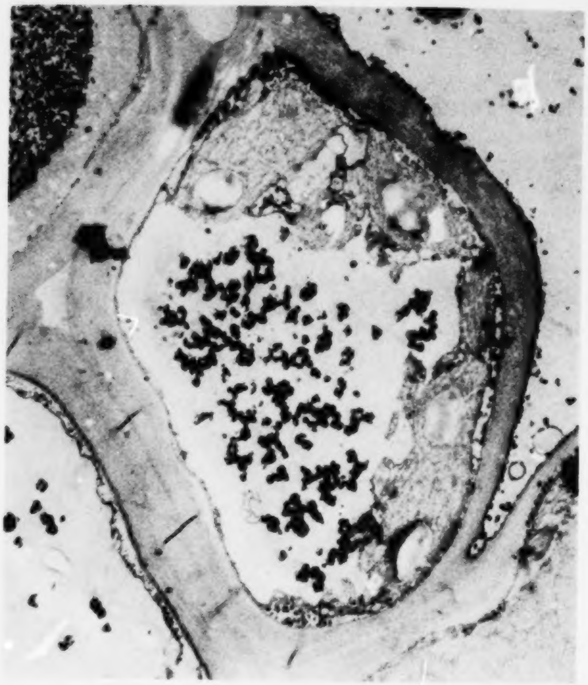

Figure 18.--Current year spruce needle mesophyll cell of damaged Fichtel Mountain sample.

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Evaluation of the Effects of Ozone and Acidic Precipitation, Alone and in Combination, on the Photosynethesis, Nutrition, and Growth of Red Spruce

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Abstract

In 1986, a five-year study was initiated to evaluate the responses of red spruce to controlled exposure to ozone and acidic precipitation. The research will evaluate the effects of the treatments on the processes, fluxes, and pools associated with carbon, water, and nutrients in the soil/tree/atmosphere system. These evaluations will be conducted on a systems level and will be integrated through the development of a simulation model. In addition, red spruce seedlings will be exposed to the same ozone and acidic precipitation treatments in the same chambers for a period of three years starting in 1987 so that comparison of effects of the treatments on seedlings and the older trees can be made. The comparison of seedling and sapling responses to the stresses is designed to evaluate and quantify the influences of plant age on the response of red spruce to ozone and acidic precipitation.

Introduction

Substantial and widespread morbidity and mortality of red spruce have been observed in high elevation forests of the northeast under circumstances indicative of a stress-related disease. Whether red spruce at lower elevations are experiencing a more subtle loss of growth and vigor is uncertain. In addition, sugar maple has exhibited decline of varying extent and intensity for several decades. Forests in the northeast are exposed to two air pollutants, ozone (O_3) and acidic precipitation, that are widespread in occurrence and have the potential, both individually and collectively, to produce impacts to forest trees. The roles, if any, of these two stress agents in the tree declines found in the northeast are not known.

In 1986, a five-year study was initiated to evaluate the effects of O_3 and acidic precipitation on red spruce. The study is funded by the Electric Power Research Institute (EPRI), the Empire State Electric Energy Research Corporation (ESEERCO), and Niagara Mohawk Power Company (NMPC). Broadly stated, the research will evaluate the effects of the pollutants on the processes, fluxes, and pools associated with carbon, water, and nutrients in the soil/tree/atmosphere system. Assessment of the effects of the treatments on carbon fixation in photosynthesis, the loss of carbon through respiration, and the allocation of carbon in growth will be a central focus of the study. Considerable emphasis will be placed on determining the influences of the treatments on the biogeochemistry of the system with studies on the leaching of nutrients from the tree canopy, the mobilization and loss of nutrients from the soil, and the alteration of tree nutrition by the input of additional nitrogen in precipitation. These evaluations will be conducted on a systems level and will be integrated through the development of simulation models.

The specific objectives of the research on seedlings funded by the U.S. Forest Service are to: 1) assess the effects of ozone and acidic precipitation on photosynthesis and growth of red spruce under exposures conducted in open-top chambers in the field; 2) produce dose-response variables for sapling and seedling red spruce exposed to the treatments in open-top chambers; 3) develop quantitative assessments of the effects of previous exposure and tree age on dose-response functions; and 4) develop guidelines for considering plant age and exposure history in the integration of the results of the research on red spruce that is being conducted in the existing programs.

Experimental Methods

Trees. The initial year of the study was devoted to obtaining the trees to be used and in construction of the research facilities. Red spruce saplings 1-1.5 m in height were obtained from the field in northern Maine, USA in May 1986. The trees were lifted from the ground, placed in pots filled with native soil, and transported to Ithaca, NY. During the summer, the 90 trees to be used in the study were selected from a group of 145 on the basis of size, previous growth history, and canopy architecture. The seedlings were germinated in late winter 1987 in vermiculite and transplanted into soil obtained from the Maine site in conetainers. The seedlings were maintained in a greenhouse under normal daylight conditions and temperatures of 20-25 C daytime and 15-17 C nighttime. They were taken to the field site in the spring of 1987 for exposure.

Exposure facilities. The trees will be exposed to controlled levels of O_3 and acidic precipitation in the field using open-top chambers. The open-top chambers are rectangular and are 7.3 m long, 2.75 m. wide, and 3.6 m high. The chambers were specially developed for use in long-term studies with large, perennial plants. The chambers have moveable tops to exclude ambient precipitation.

Treatments. The experiment will be a 4 x 3 factorial, conducted in split plots with O_3 treatments as whole plots and simulated rain treatments comprising the split plots. The four treatment levels of O_3 are charcoal-filtered air which will have the lowest concentration of O_3, ambient air, and ambient air to which O_3 will be added to produce concentrations approximately 1.5 and 2.0 times the ambient concentrations. On a daily basis, fumigations will be conducted from sunrise until sunset. Exposures will begin after bud-break and continue until approximately the first week

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in October or the first hard frost, whichever comes first. Three subplots will be established within each chamber. The subplots will receive acidic precipitation treatments of pH 5.1, 4.1, or 3.1.

Physiological effects. Assessments of net photosynthesis, carbon allocation, and growth of the saplings will be conducted throughout the course of the study. During the period of shoot elongation, weekly assessments will be made of plant height and elongation of selected shoots. Cuvettes large enough to enclose the whole above-ground portion of the tree will be used to evaluate net photosynthesis, respiration, transpiration, and stomatal conductance of red spruce. The cuvettes will enclose the trees for approximately 24 hours per sample period to calculate the uptake of CO_2 in the light (net photosynthesis), the release of CO_2 in the dark (respiration), and the total water loss (transpiration) from the tree. Each tree will be monitored for 15, 24-hour cycles between bud-break and the start of dormancy. Three weighing lysimeters will be located in each chamber containing red spruce, one in each of the simulated rain subplots, to provide additional information on water use.

The seedlings will be evaluated for rates of net photosynthesis using an ADC portable photosynthesis unit during the first field season. The trees will be sampled every four weeks after the exposures begin and at that time will be harvested to determine total dry weights of needles, stems, and roots. A subsample of trees will be used to determine projected needle areas. In the second and third years of exposures larger theremoelectrically cooled cuvettes in an open-type gas exchange system will be used to assess the rates of net photosynthesis.

Biogeochemistry. The effects of the pollutant treatments on the biogeochemistry of the two species of trees will be assessed. The physical and chemical properties of the soils will be defined prior to the initiation of the treatments and annually during the course of the study. Estimates of seasonal element uptake will be made to assess the effects of the treatments on the nutrition of the trees.

The combination of O_3 and acidic precipitation could lead to increased leaching of magnesium, potassium and organic anions from the foliage of the trees, with possible consequent effects on foliar nutrition and nutrient cycling. Changes in foliar leaching induced by the treatments will be evaluated by comparing the chemistry of throughfall and freefall precipitation.

Changes that occur in the chemistry of water as it passes through the soil will be determined by collecting water from 10 and 20 cm depths in the soil profile and from the base of the weighing lysimeter. Samples will be analyzed for pH, dissolved aluminum fractions, and major anions and cations.

Modeling. Statistical and simulation modeling will be used to assess and describe the effects of the treatments. The modeling approaches are different in technique, but complementary. Statistical models will be used to describe the relationships between non-destructive measures of growth and variables such as foliar area and mass. These models are essential for the estimates of photosynthesis and respiration that will be made in the physiology studies. Statistical models will also be developed to describe the responses of growth and physiological variables to the ozone and acidic precipitation treatments.

A simulation model will be built to describe the relationships among photosynthesis, respiration, nutrition, and water use, how these processes are affected by the treatments, and how these effects ultimately result in altered growth. The simulation model will initially provide a conceptual framework for the formulation of hypotheses regarding the interrelationships of plant components and processes and how they are affected by the treatments. Ultimately, the models can be expanded and used to predict mechanistically tree growth under conditions in the field.

Preliminary Results

Dimension analysis. In the study, measurements of whole-tree photosynethesis and transpiration of red spruce will be made over a four year period and the rates expressed on a unit leaf area or leaf mass basis. Since the length of the study and limited number of trees necessitate the use of non-destructive methods for estimating leaf area and mass, it will be necessary to have estimates of these variables for the entire crown as well as by age-class. Dimension analysis was used to develop prediction equations for leaf area or mass based on easily obtained, non-destructive measures of tree growth.

Twenty trees were selected at random from those obtained in Maine and harvested for dimension analysis using the methods and notation of Cannell (Cannell 1974). Branches were separated into mainstem or lateral, lengths of branches were measured by age-class, needles were removed from a sample of branches and projected leaf area and weight determined. Other measurements included number of nodal branches, number of internodal branches, dry mass of needles on the mainstem, number of needles per branch, number of needles originally present (determined from needle stubs), and the length and diameter of the terminal at each node on the trunk. All measurements were made by age-class.

Regression analyses indicate that rather simple relationships can be used to predict leaf mass from other measures of tree growth. It is necessary to make separate estimates of lateral and mainstem leaf mass however, as the fundamental relationships between needle area and tree growth are quite different for the two classes. In most cases, the allometric equation (France and Thornley 1984) (a ln-ln transformation of the cumulative mass vs cumulative growth) resulted in a significant relationship with an R^2 greater than 0.9. It should be noted that variation exists in the data since the randomly selected trees represented the full range of thin to bushy forms present in the experimental population. Even though the R^2 is high, there is a potential for considerable error in the prediction. Based on these results, we are currently using the natural log of cumulative tree height to predict leaf mass.

Physiology. Development and testing of equipment for use in the physiological studies took place in 1986. Tests of the weighing lysimeters indicated changes in weight of approximately 100 g in a 350-400 kg soil/tree system could be detected. These hourly averages of mass of the systems were suitable for determining rates of transpiration from the trees. Rates of transpiration were in agreement with those calculated by mass balance technique with the whole-tree cuvette.

The average stomatal conductance (k_s) and transpiration (T_s) were assessed for two 1986 mainstem shoots at each of four nodes, 1984-86, on two trees in the field. The k_s and T_s trends of 1986 mainstem shoots at different nodes during August-September 1986 were very similar. At approximately equal VPD, light intensities, and temperatures, there was a decrease in k_s from the 1986 node to the 1983 node in both trees. This trend was always present regardless of the day on which measurements were made.

Whole-tree cuvettes were used to screen 109 trees for rates of net photosynthesis under conditions of full sun and between 20-30 C (cuvette temperature). The rates of net photosynthesis ranged from approximately 1 to 12 mg CO_2 g^{-1} dry weight hr^{-1}. The distribution was normal after the outliers were excluded.

Growth chamber studies were conducted to assess the effects of light intensity and temperature on net photosynthesis and the effects of light intensity and vapor pressure deficit (VPD) on stomatal conductance. Net photosynthesis was monitored in three age-classes of shoots, 1984, 1985, and 1986, for response to temperatures of 12, 16, 24, and 28 C and at light intensities from 0 to 800 μ mol s^{-1} m^{-2}. The highest rates of net photosynthesis were achieved at 16 C and 800 μ mol s^{-1} m^{-2} for all three age-classes. The rates of respiration in the dark increased with increases in temperature. The light compensation point at 28 C was approximately 50 μ mol s^{-1} m^{-2} and declined to about 10 μ mol s^{-1} m^{-2} at 12 C.

Stomatal conductance was monitored in three age-classes of shoots, 1984, 1985, and 1986, for response to light. The minimum k_s (cm s^{-1}, ± 1 S.D.) prior to lights on were 0.09 ± 0.02 (1986), 0.09 ± 0.08 (1985), and 0.12 ± 0.01 (1984). Approximately 1.5 to 2 hours after the lights were turned on (light intensities between 800 and 1400 μ mol s^{-1} m^{-2}), k_s had reached a maximum in all three age-classes (0.29 ± 0.02, 1986; 0.21 ± 0.05, 1985; and 0.35 ± 0.04, 1984).

The relationship between k_s and VPD among three age-classes of shoots (1984-86) was examined in a controlled environment over several weeks. At low VPD (0.5-0.7 kPa), k_s was at a maximum or increased to a maximum with increasing VPD in all three age-classes. Maximum k_s in the three age-classes occurred in the three age-clases occurred between VPD of 0.7 kPa and 1.25-1.5 kPa.

Above light levels of 100 to 200 μ mol s^{-1} m^{-2}, within a temperature optimum of 17 to 30 C, and at similar VPD, k_s varied with respect to node position and age-class in the red spruce trees examined here. This, as well as substantial differences in k_s due to orientation and origin (mainstem vs lateral) of shoots, has been documented in other conifers, e.g., Scots pine and Sitka spruce (Beadle et al. 1985a; Beadle et al. 1985b; Laverenz et al. 1986). At a given node/age-class/orientation/shoot-type, k_s has also been found to vary seasonally (Beadle et al. 1985b). If treatment effects in this study are manifested as changes in crown k_s , it may be desirable to determine whether the effect is proportionally the same over the identified components of variation in crown k_s (e.g. node position) or whether a particular component is more or less affected.

Evaluation of the photosynthetic rates of the saplings for the summer of 1987 is not yet finished. However, in the seedling study the photosynthetic data for the harvests conducted after four and eight weeks of exposure indicted no effects of either ozone or acidic precipitation on net photosynthesis. This is not surprising considering the lack of response of red spruce seedlings to longer exposures of ozone alone (Weinstein and Alscher personal communication) or ozone in combination with simulated acidic precipitation (Taylor et al. 1986).

Modeling. The modeling effort began with development of a model design which conceptualized the processes important to tree growth, the interrelationships among these processes, the types of data generated by the experiment, and the summary variables which will be measured and against which the model behavior will be tested. The model is being constructed in 10 separate modules. The development of modules independently, with inter-linking in a later step, facilitates error testing and verification.

At present the photosynthesis and soil nutrient process modules have been constructed and are being tested, the carbon allocation module has been devised and is presently being coded, and the root growth and nutrient uptake modules are under development.

The photosynthesis module has been constructed following the conceptual development contained in the models of Running (Running 1984; Lohammar et al. 1980). The module uses hourly environmental input data to calculate the amount of gross carbon fixation each hour in each of four year classes of leaf tissue. The rate of fixation is considered to be proportional to the resistance to carbon dioxide flow into the leaf at the stomata (leaf conductance) and at the cell membrance (mesophyll conductance). The light available during each hour is dependent upon the time of year, time of day, and probability of cloudiness. The rate at which this light can be used to convert CO_2 to fixed carbon molecules is dependent upon the maximum photosynthetic rate of the tissue, the projected air temperature, and the effect of this temperature on water vapor pressure deficit under conditions of lower water availability. From this calculation an annual carbon fixation from the whole-plant leaf tissue is computed. The module has an hourly time step and is designed to require a minimal amount of empirical input data. The data being collected from the experimental trees will provide a test of the assumption used in the model formulation.

Comparisons were made between predictions of this module and whole-tree carbon uptake from field measurements taken during August, when each tree was screened for photosynthetic rate. The mean rates projected by the module are similar to the mean field values. Further, the range of values produced by the module compared quite favorably with the field values within one standard deviation of the mean. It is believed that the differences between model projections and field behavior are related to inaccuracies in estimating leaf mass and surface area of the field trees. Methods for improving these estimates are being explored.

A conceptual outline of a soil ion leaching module has been constructed, following the piston flow formulation of Levin 1964, modified by Addiscott, 1977 and Addiscott and Wagenet 1985, and the chemical equilibrium considerations of Cosby et al. 1984. This module will use data on input rainfall chemistry and soil water flow properties to predict concentrations and quantities of major ions in water collected from lysimeters at two soil depths and flow out of the bottom of the pots.

The soil is assumed to be segmented into 4 sections, each internally homogeneous: fresh leaf litter (2 cm deep), forest floor (5 cm deep), upper mineral layer (10 cm deep), and lower mineral layer (40 cm deep). Nutrient mineralization and the exchange of hydrogen ions for calcium ions are assumed to be the dominating processes to be followed in the forest floor layer. The mineral horizon chemical equilibria calculations will be dominated by the exchange of calcium for aluminum and the exchange of hydrogen for silica. At the bottom of each layer the outflow of H^+, Ca^{++}, NH_4^+, NO_3^-, SO_4-, Si, K^+, Mg^{++}, and Al^{+3} will be projected.

The allocation of newly synthesized carbohydrate to different tissues of the tree is perhaps the least understood process that the model will attempt to simulate (Agren 1981). The challenge is to assign carbohydrates to various tree compartments (e.g., needles, stems, roots) in the proper form (e.g., storage, structure, wood) and to account for respiration loss. The distribution of photosynthate will strongly affect the growth predictions made by the model for any given set of conditions; furthermore, the seasonal pattern of allocation evident in conifers (Drew 1982) may interact with the temporal variability of treatments.

The compartments, flow equations, and the capacity to accept phenologic inputs (e.g. time of bud break) are useful concepts in the CERES (Dixon et al. 1978) and PT (Agren and Axelsson 1980) models. However, modifications to these models are required to simulate seasonal dynamics of carbon allocation, and allow the pattern to change in response to stress. A module was constructed similar to PT and incorporating the partitioning scheme of Reynolds and Thornley 1982. Although the test version of the module did exhibit seasonal fluctuations and responses to environmental conditions, it was somewhat difficult to control the oscillations between root and shoot growth. In addition, the module was probably too complex for simulating a poorly undersood process. Another allocation module being tested allows for flexibility in the partitioning pattern without introducing complex or artificial schemes. New carbohydrates are allocated according to sink demand (e.g. growth rate or storage rate) and the priority of the sink since it has been suggested that sinks are more important in the control of partitioning than sources or transport functions (Gifford and Evans 1981).

Summary

The integrated approach that this research program has adopted will provide information on the systems-level effects of 0_3 and acidic precipitation on the physiology, growth, and biogeochemistry of red spruce. It will also provide information on the response of different aged red spruce to ozone and acidic precipitation stresses. The development of a simulation model serves as the framework for identifying, integrating, and formulating the components of the project. In addition, the objectives of the program have led to the adoption or development of research tools such as new open-top chambers, weighing lysimeters and whole-tree cuvettes.

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Effect of Simulated Acid Rain and Ozone on Red Spruce Seedlings: An Interim Report

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Abstract

*Red spruce (**Picea rubens** Sarg.) seedlings are being exposed to ozone (control; 0.15 ppm, 6 h/d; 0.15 ppm, 6 h/d + 0.07 ppm, 18 h/d) in combination with simulated acid rain (pH 4.5, 4.0, or 3.5) applied once (12.7 mm) per week. Plants are being harvested at 7-week intervals (five harvest dates) to examine the effects of treatment on growth, photosynthesis, carbohydrate levels, and foliar leaching. Only data on growth and net photosynthesis from the first two harvests (7 and 14 weeks) are available at this time. The only variable significantly affected by treatment was new-stem dry weight in the first harvest. New-stem dry weight was higher at pH 4.0 than at 4.5 or 3.5, and higher at 24 h of ozone than at the control or 6 h of ozone. No interactive effects of the two pollutants were observed.*

Introduction

The USDA Forest Service's Spruce-Fir Cooperative Research Program was set up to study the decline and mortality of red spruce (*Picea rubens* Sarg.) in high-elevation spruce-fir forests of the Appalachian Mountains in the eastern United States. One major objective of the program is to determine if there is a relationship between acidic deposition, in combination with other pollutants, and forest damage. This is an interim report of a study that examined the possibility of such a relationship. The objective of the study was to determine whether treatment of red spruce seedlings with ozone and simulated acid rain, alone and in combination, affects root and top growth, photosynthesis, concentrations of mineral elements and carbohydrate reserves, and foliar leaching.

Methods

Since April 20, 1987, 1-year-old red spruce seedlings in 10.2 x 10.2 x 35.6-cm containers were grown in nine CSTR chambers (45 seedlings per chamber) with a day:night temperature regime of 25: 20°C, a 16 h-light/8 h-dark photoperiod, and a light intensity of 225 μE. Seedlings are watered twice a week. The chambers are arranged in three blocks of three chambers with different ozone treatments: charcoal-filtered air; 0.15 ppm ozone for 6 h per day (during middle of light period); and 0.15 ppm ozone for 6 h per day (during middle of light period) and 0.07 ppm ozone during the remainder of the daily cycle.

At the start of the study there were three groups of 15 seedlings in each chamber, each group receiving a different simulated rain treatment, pH 3.5, 4.0 or 4.5 (SO_4^{2-}:$NO_{2,}^{-}$, 2:1). Seedlings are removed from the chambers once each week for application of 12.7 mm of simulated rain (application takes approximately 40 min). The 15 seedlings in each treatment group were divided into five subsets of 3 seedlings for harvest on five dates: June 8, July 28, September 15, and November 1, 1987, and March 2, 1988.

In summary, the experimental design is a 3(ozone) x 3(rain acidity) x 5(harvest time) factorial replicated three times with three observations per replication.

The week prior to a harvest date, net photosynthetic rate of each seedling is measured with a Li-Cor Li-6200 system and a 1/4-L curvette. The rates of needles on 6.5-cm segments of two upper branches are measured and averaged. Then the needles on the segments are removed, dried, and weighed. Net photosynthetic rate is expressed as mg CO_2/hr/g DW.

On each harvest date, terminal plant growth and diameter of each seedling are measured. In addition, on the Sept. 15 and Nov. 3 harvest dates, lateral shoot sections will be taken for leaching tests. Then the seedlings are dissected into roots, old and new stems, and old and new needles. The parts are dried at 80°C and weighted. Needles and roots are ground to prepare them for chemical analysis.

Five-centimenter segments from the terminal ends of the two uppermost lateral shoots of each seedling will be taken randomly for the leaching tests. The segments will be immersed tip end down in 25 ml of leaching solution (same pH as the rain solutions) in 30-ml plastic bottles with the cut end above the surface of the solution. After 24 h of treatment on a shaker, the shoots will be removed and the conductivity and pH of the solutions determined within 48 h. Solutions are then refrigerated and, as soon as possible, anlayzed for mineral elements by inductively coupled emission spectrophotometry (ICP) by the Research Extension Analytical Laboratory, Ohio Agricultural Research and Development Center (OARDC), Wooster, Ohio.

Subsamples of ground old and new needles are analyzed for mineral elements by the OARDC laboratory. The subsamples are dry-ashed overnight at 500°C and the ash dissolved in 2.4 N nitric acid. The solution is analyzed for nutrient ions by ICP. Other subsamples are analyzed for nitrogen by a semimicro-Kjeldahl procedure.

Subsamples of ground old and new needles and root tissue are analyzed for total nonstructural carbohydrates (sugars and starch) (Dickson 1979). Sugars are extracted with a methanol-chloroform-water solution. The residue contains starch. After the pigmented chloroform fraction is removed from the extracting solution, a subsample of the extract is mixed with anthrone reagent to hydrolize the sucrose. Total sugar (glucose) is determined

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colorimetrically. Starch in the residue is gelled, then hydrolyzed enzymatically with a combiantion of Diazyme L-200 and alpha amylase. Starch (measured as glucose) is determined colorimetrically by the glucose oxidase method.

Results

Results to date are for red spruce seedlings harvested on June 8 and July 28, 1987 (succeeding harvests will occur on September 15, November 2, and March 2). This report includes information on height and diameter growth, dry weight of plant parts, and net photosynthetic rate. Analyses of plant tissue for carbohydrate and mineral elements were not available when this report was prepared. Leaching tests of foliage were not conducted on seedlings from the first two harvest dates.

First harvest, June 8 (7 weeks of treatment).--There were no significant interactions between ozone and rain treatments; therefore, growth data and net photosynthetic rates were pooled (Table 1). New-stem dry weight was the only growth variable significantly affected by rain treatment. New-stem dry weight was significantly higher at pH 4.0 than at pH 4.5 and 3.5. The greatest mean total seedling dry weight occurred at pH 4.0.

Table 1.--Effect of rain acidity and ozone on growth and net photosynthetic rate of red spruce seedlings (mean values: n = 27)

			Dry weight						
Treatment	Height growth	Diameter growth	New needles	New stem	Old needles	Old stem	Roots	Total	Net photo-synthetic rate[a]
	cm	mm	g						
			FIRST HARVEST						
Rain acidity (pH)									
4.5	11.8	1.53	3.15	0.69	0.78	1.95	0.77	7.34	5.69
4.0	12.3	1.47	3.46	0.93	0.91	2.02	0.87	8.18	5.13
3.5	16.1	1.50	2.84	0.55	0.82	1.92	0.78	6.91	5.18
	NS	NS	NS	**	NS	NS	NS	NS	NS
Ozone (h)									
0	10.6	1.53	3.05	0.61	0.82	1.97	0.77	7.22	5.35
6[b]	13.6	1.50	3.00	0.66	0.85	1.92	0.79	7.22	5.45
24[c]	15.9	1.46	3.39	0.89	0.84	2.01	0.86	7.90	5.20
	NS	NS	NS	*	NS	NS	NS	NS	NS
Range of SE	0.7-6.5	0.13-0.23	0.27-0.54	0.07-0.31	0.09-0.19	0.18-0.32	0.09-0.22	0.62-1.25	0.24-0.77
			SECOND HARVEST						
Rain acidity (pH)									
4.5	19.5	3.35	6.36	2.64	0.70	3.79	1.79	15.27	5.35
4.0	17.4	3.52	6.09	2.51	0.72	3.60	1.80	14.72	5.84
3.5	20.1	3.73	7.07	3.28	0.75	3.96	1.92	16.97	6.08
	NS	NS	NS	NS	NS	NS	NS	NS	NS
Ozone (h)									
0	18.9	3.51	6.67	2.60	0.83	4.03	1.84	15.97	5.88
6	17.7	3.67	6.58	3.27	0.62	3.32	1.79	15.58	5.84
24	20.4	3.42	6.26	2.59	0.72	4.01	1.88	15.42	5.57
	NS	NS	NS	NS	NS	NS	NS	NS	NS
Range of SE	1.0-2.3	0.17-0.34	0.39-0.74	0.16-0.82	0.05-0.16	0.30-0.59	0.18-0.32	0.92-1.76	0.30-0.68

[a] $mgCO_2/hr/g$ DW.
[b] 6 h at 0.15 ppm.
[c] 6h at 0.15 ppm + 18 h at 0.07 ppm.
* $= P < 0.05$; ** $= P < 0.01$; NS = not significant.

New-stem dry weight also was the only growth variable significantly affected by ozone treatment. This variable was significantly higher in the 24-h ozone treatment [0.15 ppm (6 h) + 0.07 ppm (18 h)] than in the 6 h-ozone treatment (0.15 ppm) or the control. The same was true for most other growth variables.

Treatments did not significantly affect the net photosynthetic rate of red spruce seedlings. There was no indication that the rate was inhibited by ozone treatment. The lower rate at pH 3.5 and 4.0 than at pH 4.5 suggested that photosynthesis may be inhibited by increasing the acidity of the rain solution.

Second harvest, July 28 (14 weeks of treatment).--Treatments had no significant effects on growth of red spruce seedlings or the net photosynthetic rate (Table 1). The data did suggest that growth increased slightly with increasing rain acidity and was inhibited slightly by ozone. Promotion of net photosynthetic rate by increasing rain acidity and its inhibition by ozone also was suggested by trends in the net photosynthetic rate.

Discussion

Ozone and acid rain did not significantly affect the growth or photosynthetic rate of red spruce seedlings over 14 weeks of treatment. A significant effect of these pollutants on new-stem growth observed after the first 7 weeks of treatment disappeared during the second 7 weeks. This probably resulted because of the changing effect of treatment on seedling growth, from stimulation to inhibition or vice versa. During the initial treatment period, a rain acidity of pH 4.0 was optimum for growth. During the second treatment period, when the total seedling biomass more than doubled, growth was greater at pH 3.5 than at less acid treatments. The fertilization effects of high inputs of nitrogen at pH 3.5 probably was the cause. The effect of ozone also changed with time. Growth data from the first harvest indicated that ozone had promoted growth while data from the second harvest suggested that growth was being inhibited.

Data from additional harvests will need to be analyzed before the combined effects of ozone and acid rain on red spruce seedlings can be assessed. No interaction between the pollutants was observed during the first two harvests. Minimal or no interaction between ozone and acid rain were observed by Reich et al. (1986) for sugar maple and red oaks; Reich et al. (1987) for white pine; and Chappelka and Chevone (1986) for white ash. A significant ozone x acid rain interaction was found in the treatment of yellow poplar with pollutants by (Chappelka et al. 1985).

Growth stimulation resulting from ozone treatment was observed in data from the first harvest. This is not unusual as positvie responses to low levels of ozone were reported by Bennett et al. (1974) and Kress and Skelly (1982).

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The Impact of Acid Rain on Fraser Fir Seedling Growth and Physiology

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Introduction

The apparent decline of spruce and fir found in the southeastern United States, as well as increased mortality and decline of European forests, has prompted considerable public and industrial concern about the possible effects of air pollution on the commercially important forests of the southeastern United States. Although commercially unimportant from a timber production standpoint, the spruce and fir forest in the southeastern United States could be a valuable bio-indicator of the possible effects of air-borne pollutants on southern commercial forests.

It has been hypothesized that the apparent decline of spruce-fir forests in the eastern United States is due to interactions among several stresses, including acid rain. In the northeastern United States, the decline of red spruce has been suggested to result, in part, from acidic deposition and heavy metals in conjuction with severe drought stress (Johnson and Siccama 1983, 1984; Tomlinson, 1983). Acidic deposition is currently considered a major environmental threat; however, the scientific evidence demonstrating effects on terrestrial vegetation is inconclusive. No studies have examined the effect of acidic rain on Fraser fir (*Abies fraseri* (Pursh) Poir.), a major component of the spruce-fir forests in the southeastern United States. This study was conducted as part of the Spruce-fir Research Cooperative and deals specifically with scientific question 2.3 - what is the effect of sulfer and/or nitrogen derived pollutants alone or in combination with oxidants on red spruce and fir morphology by the mechanism of carbon allocation and physiological processes. Specifically this study determined the impact of simulated acid rain on the biomass accumulation, growth, and physiology of Fraser fir seedlings.

Materials and Methods

Three-year-old Fraser fir were obtained from a grower in Whitetop, Virginia, and planted in 10 cm diameter plastic pots filled with an unclassified mountain Spodosol collected from under a high elevation (1220 m) spruce stand near Mountain Lake in Giles county, Virginia. The upper 30 cm of mineral soil was collected and thoroughly mixed before placement in the pots. Seedlings were placed in a greenhouse and maintained under a 16-hour photoperiod using supplemental lighting with high pressure sodium vapor lamps. The greenhouse was supplied with charcoal filtered air to remove ambient ozone and temperatures ranged from 20 to 35°C. After a 2-week acclimation period, seedlings were randomly assigned to three acid rain treatments (pH 3.0, 4.3, or 5.6). Acid rain was applied to the seedlings using a simulator developed on the principle of droplet formation from needle tips (Chevone et al. 1984). Ionic concentrations were similar to the average ambient rainfall occurring in southwestern Virginia; solutions were prepared as described by Chevone et al. (1984). Simulated rain acidity was adjusted by addition of 1 M H_2SO_4 + 0.5 M HNO_3. Rain was applied to the seedlings at a rate of 1.25 cm/hr for 1 hour, twice weekly for 10 weeks.

Ten seedlings from each of the treatments were used to measure gas exchange prior to, after 5 weeks, and at the end of the 10-week treatment period. A branch from each seedling was stripped of a small ring of needles, tagged at that point, and emergent needles plucked off to ensure that repeated net photosynthesis (Pn), transpiration (Ts), and needle conductance (Cs) measurements were taken on the same needles. Seedlings were placed within an environmentally controlled chamber and allowed to equilibrate for at least one hour before measurements began. Photosynthesis, Ts, and Cs were measured with a portable photosynthesis system (LI-6000, LI-COR, Inc., Lincoln, NE) using a quarter-liter cuvette. Average environmental variables within the cuvette were 20 ± 5.9% RH, 30 ± 2°C, 600 ± 20 μMol $m^{-2}s^{-1}$ PPFD, and 348 ± 22 ppm CO_2.

At the end of the 10-week treatment period, needles used to measure photosynthesis were removed and projected needle surface area was taken with a LI-3000 Portable Area Meter (LI-COR, Lincoln, NE). Root surface area of the same seedlings was also measured with the area meter. The needles used to measure photosynthesis, new growth, shoots, and roots were dried in a 65°C drying oven for at least 24 hours before dry weights were measured. Water-use efficiency (WUE) was calculated as the ratio of Pn (mg CO_2 $m^{-2}h^{-1}$) to Ts (mg H_2O $m^{-2}h^{-1}$) for each seedling.

Soil from ten pots per acid rain treatment were randomly selected and analyzed for major cations, NO_3-, organic matter and pH. Cations were extracted with a 0.05 N HCl + 0.025 N H_2SO_4 extraction and analyzed by inductively coupled plasma spectroscopy, similar to the atomic absorption method. Soil NO_3- was determined with a 2.5:1, 0.02 M $CuSO_4$:soil extraction and measured with a NO_3- electrode. Soil organic matter content was determined using a 0.67 M $Na_2Cr_2O_7 \cdot H_2O$:soil extraction and measured colorimetrically. The pH of the soil was measured using a 1:1 water:soil paste.

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Growth variables were measured on 50 seedlings and gas exchange variables were measured on 10 seedlings per rain pH. Duncan's Multiple Range Test was used to determine significance among treatments. All data were analyzed for homogeneity of variance, and no transformations were necessary.

Results

Simulated acid rain resulted in no significant differences in biomass variables (Table 1). Shoot weight appears to exhibit a decreasing trend with increasing rain acidity; however, all other variables varied by less than 2.5% in response to changing rain acidity. Simulated acid rain of 3.0 resulted in significantly higher root surface area and root surface to root weight ratio when compared to the 4.3 pH treatment (Table 2).

Table 1.--Biomass of 4-yr-old Frasier fir after exposure to 10 wks of simulated acid rain (n = 50)[1]

	Acid Rain (pH)		
Item	3.0	4.3	5.6
Shoot Wt (g)	3.51	3.55	3.81
Root Wt (g)	1.66	1.58	1.70
New Shoot (g) Growth	0.789	0.719	0.782
Root/Shoot Ratio	0.680	0.722	0.683

[1] No means were significantly different (alpha = 0.05).

Table 2.--Root surface area, weight, and area/wt ratio of 4-yr-old Fraser fir after 10 wks exposure to simulated acid rain (n = 10)[1]

	Acid Rain (pH)		
Item	3.0	4.3	5.6
Root Wt (g)	1.92a	1.77a	1.72a
Root Surface Area (cm^2)	169.2a	136.7b	146.4ab
Root area/ Root Wt ratio (cm^2/g)	88.8a	77.5b	85.8a

[1] Means within the same row followed by the same letter are not significantly different (alpha = 0.05).

Although no significant differences among treatments occurred for biomass and growth variables, with the exception of the rain effect on root surface area, significant differences did occur for the physiological parameters measured. Transpiration was significantly lower at pH 3.0 than pH 5.6, although pH 4.3 resulted in the lowest Ts (Table 3) after 5 weeks exposure. At the end of 10 weeks, Ts was not significantly different among treatments despite a decreasing trend with increasing rain acidity. Seedlings exposed to a rain pH of 5.6 exhibited significantly higher Cs than seedlings exposed to 4.3 pH rain after 5 weeks, but this was not significantly higher than pH 3.0. At the end of the study, Cs was not significantly different among treatments, exhibiting a similar response as observed with Ts. Photosynthesis was not significantly affected by the simulated acid rain treatments (Table 3); however, a significant increase in WUE at a pH of 3.0 was observed as compared to pH 5.6 treatment after 10 weeks.

Table 3.--Transpiration, conductance, photosynthesis, and water-use efficiency (WUE) of 4-yr-old Fraser fir after 5 and 10 wks of simulated rain exposure (n = 10)[1]

	Acid Rain (pH)		
Item	3.0	4.3	5.6
Needle Conductance (cm/s)			
5 wks	0.784ab	0.673b	0.953a
10 wks	0.352a	0.368a	0.375a
Photosynthesis ($mgCO_2cm^{-2}h^{-1}$)			
5 wks	0.097a	0.090a	0.097a
10 wks	0.067a	0.066a	0.057a
Transpiration ($mgH_2O\ cm^{-2}g^{-1}$)			
5 wks	24.15b	20.67c	27.50a
10 wks	17.89a	19.71a	21.47a
WUE (mg CO_2/mg H_2O)			
5 wks	0.0040a	0.0043a	0.0036a
10 wks	0.0037a	0.0034ab	0.0027b

[1] Means within the same row followed by the same letter are not significantly different (alpha = 0.05).

Simulated rain of pH 3.0 significantly decreased the pH of the soil as compared to either pH 5.6 or 4.3 rain treatments which did not differ significantly (Table 4). Nitrate concentration in the soil exhibited an increasing trend with decreasing rain pH but values were not statistically different. A significant reduction in the amount of potassium and magnesium was also evident as rain acidity increased (Table 4).

Table 4.--Analysis of soil components after 10 wks of simulated acid rain exposure[1]

Item	Acid Rain (pH)		
	3.0	4.3	5.6
pH	4.2b	4.6a	4.6a
P (ppm)	3.0a	3.0a	2.4b
K (ppm)	17.6b	20.5a	19.1a
Ca (ppm)	81.6a	86.4a	82.8a
Mg (ppm)	10.7b	13.7a	12.8ab
OM (%)	3.3a	3.1b	3.4a
NO_3 (ppm)	9.1a	8.4a	8.2a

[1] Means within the same row followed by the same letter are not significantly different (alpha = 0.05).

Discussion

A lack of any significant effect on growth of biomass accumulation due to short-term simulated acid rain application, as observed in this study, has been reported by various other authors (Neufeld et al. 1985, Irving 1983, Amthor 1984, Seiler and Paganelli 1987). Lee and Weber (1979) indicated varying responses of eleven woody species to the effects of simulated acid rain, yet none of the species exhibited significant inhibition of top growth. Wood and Bormann (1977) reported a short-term increase in the productivity of eastern white pine (*Pinus strobus* L.) after exposure to simulated rain of pH 2.3. MacDonald et al. (1986) found increases in the shoot biomass of jack pine (*Pinus banksiana* Lamb.) when exposed to decreases in simulated rain pH. Our study shows a similar response in the slight stimulation of new growth in response to increasing rain acidity (Table 1). This may indicate a fertilization effect at the lower pH due to the use of nitrates in preparation of the rain solution. Although soil analysis did not indicate significant NO_3^- differences among rain treatments, a slight increase in NO_3^- concentration was observed for the lower pH treatments (Table 4).

After 5 weeks of simulated acid rain treatments at pH 3.0, seedling Ts was significantly decreased from the 5.6 pH treatment. Rain pH of 4.3 decreased Ts more than rain pH of 3.0 (Table 3). A decreased Ts rate may actually enhance productivity if photosynthesis is maintained, due to decreased water loss. A significant reduction in Ts was no longer evident after 10 weeks of treatment though trends remained the same.

Needle Cs was also significantly lower after 5 weeks for seedlings treated with 4.3 pH rain. Neufeld et al. (1985) reported a decrease in the stomatal conductance of sweetgum (*Liquidambar styraciflua* L.) only after exposure to rain treatments below 2.0 pH. Leaf conductance for yellow-poplar (*Liriodendron tulipifera* L.) sycamore (*Platanus occidentalis* L.) and black locust (*Robinia pseudoacacia* L.) was not affected. A lowering of conductance at lower pH rain levels may be due to a loss of turgor by guard or subsidiary cells, a disruption of the ionic balance in the guard cells caused by excess H^+ ions, leaching of nutrients (especially K^+) from guard cells, or a reduction in photosynthetic capacity (Neufeld et al. 1985).

No significant reductions in Ps were observed in this study due to simulated acid rain (Table 3); however, simulated rainfall of pH 3.0 resulted in the highest WUE (0.0037 mg CO_2/mg H_2O) after 10 weeks. A higher WUE may also be the result of the hypothesized fertilization effect noted earlier, and would certainly decrease the susceptibility of Fraser fir to periodic drought stress.

Summary and Conclusions

With the exception of an increase in root surface area at a pH of 3.0, simulated acid rain caused no significant change in Fraser fir seedling growth. This is consistent with many previous reports on other tree seedlings. Water-use effiency was increased in seedlings exposed to a rain pH of 3.0; however, no other physiological parameters changed significantly as a result of the acid rain treatments. These results suggest that Fraser fir may be insensitive to short exposures of acid rain as low as pH 3.0.

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Red Spruce Research Within the UVM Forest Physiology Lab: An Historical Overview

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Abstract

The Forest Physiology Laboratory at the University of Vermont has been investigating several aspects of the red spruce decline phenomenon since 1984. In a preliminary field survey, numerous stand and site characteristics were measured in an attempt to determine what factor(s) were best correlated with related severity of decline symptomology. Elevation and soil concentrations of lead and copper were most strongly related to the severity of decline. Subsequent research has focused on identification of the physiological systems potentially involved. Preliminary investigations indicate that water-regulatory and/or energy systems may be altered in declining spruce. Current research is aimed at measuring photosynthesis, seasonal carbohydrate levels, and transpiration in naturally-grown and artifically-raised seedlings from high and low elevation spruce stands.

The Forest Physiology laboratory at the University of Vermont has assigned itself the task of researching physiological responses of some native forest trees to stress-inducing factors. Because of recent emphasis on the phenomenon of red spruce (*Picea rubens* Sarg.) decline, we have focused in the last several years on seeking an understanding of basic physiological processes related to decline in this species. Our research in this area began in 1984 and continues today. During this time period our research group, including at various times University of Vermont faculty, staff and graduate students, and collaborating scientists from other institutions, has investigated a number of aspects of spruce decline. These investigations, which began with a broadly based field survey and currently include a study of energy and water systems in spruce, have provided insight into the extent of spruce decline, have identified physiographic factors which are correlated with observed levels of decline symptoms, and are beginning to shed light on the potential role of certain physiological systems we believe may be involved in the decline. The purpose of this paper is to provide an overview of our research findings relative to red spruce over the past 3 years, and to highlight current research efforts which have evolved from these findings.

Summary of Red Spruce Research

Relationship Between Physiographic Stand Characteristics and Extent of Decline in Red Spruce Stands

We initiated our red spruce research in 1984 when numerous reports of red spruce decline and mortality were appearing in the literature. At that time there was no consensus among scientists concerning possible causes, or even the degree or geographical extent of the decline. We believed that the most appropriate beginning to a red spruce decline research program was to undertake a broad-based preliminary survey of red spruce stands in Vermont, the goal of which was to collect as much information pertaining to the physiographic and biologic aspects of spruce stands as possible. We perceived that results from this type of preliminary investigation would allow increased efficiency in subsequent research activities since it would allow us to concentrate on factors most likely to be decline-related.

In summer 1984, in cooperation with Dr. Robert Gregory and other scientists from the USDA Forest Service, Northeastern Experiment Station, we selected, from numerous candidates, 20 stands for inclusion in this study. The 20 were chosen to represent a wide variety of elevations, stand ages, and geographic locations in the northern Green Mountains of Vermont. During late summer 1984 we visited each stand and measured numerous physiographic and vegetative characteristics. The parameters measured were stand aspect, slope, slope-position and relative drainage; average stand age, percent crown cover, basal area, and seedling mycorrhizal levels; and soil depth, texture, pH, and concentrations of the 16 nutrient and metal ions in the upper horizons. Additionally we developed a stress-rating for the spruce component of each stand. Results of this study are presented in Donnelley *et al.* (1985), and are briefly summarized here.

Magnitude of stand stress symptoms increased significantly with elevation. We logically presumed that this stress is most likely caused by factors which themselves vary with elevation. This includes a host of climatic, edaphic and biologic parameters, most of which we did not measure. However, based on those we did measure, forest-floor concentrations of copper and lead are two interesting possibilities. O_2-horizon concentration of these elements increased with elevation, and both were correlated with stand stress. The relationship between these elements and stand stress might be spurious via their mutual relationships with elevation. But, because these elements are known to be phytotoxic at high levels, are atmospherically vectored, and because precipitation increases with elevation thus increasing their deposition, the role of these materials as possible contributors to spruce decline warrants further investigation.

We found abundant seedling mycorrhizae in all stands. This was somewhat surprising because others have reported an absence of mycorrhizae in declining red spruce (Vogelmann 1982). We did not identify the species of mycorrhizal fungi found, nor did we look for mycorrhizae on the roots of mature trees. But they were certainly present in all seedlings and, in fact, their abundance increased with increasing overstory stress. There are reports in the literature (Stehl cited in Meyers, 1974, for example) which indicate that mycorrhizal associations are enhanced on poor sites. Since poor cites are stress inducing, both mycorrhizae and stress

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levels might be responding to site quality.

Significantly, we found numerous factors which were not correlated with stand stress. These include soil pH, texture and depth, stand aspect, age, basal area, and slope position, and the relative abundance of spruce within the stand.

While all data from the above study have proved valuable in formulating and evaluating red spruce decline research, only one factor, elevation, emerged as irrefutably linked with level of decline symptoms observed. An additional observation made during the course of the study, although not quantified, appears to be of importance. We noticed in virtually all cases, even in extremely degraded high elevation spruce stands, that decline was limited to the spruce component. Other stand components, including balsam fir (*Abies balsamea*) and paper birch (*Betula papyrifera* var. *cordifolia*) and understory herbaceous plants and ferns were relatively healthy. In fact, in some stands these other species, in various proportions, appeared to be replacing the spruce component. This observation raised the issue of differential physiological response to stress, and we posed the question, "What physiological factor or factors, inherent in the biology of red spruce, makes this species respond uniquely to whatever causative stress-inducing factor exists in these stands?" We believed then, and continue to believe, that resolution of this question is an absolute requisite to understanding the nature of, and causative factors associated with, decline in this species.

In pursuit of this question, we selected two physiological systems, *a priori*, whose normal functioning we believe are of paramount importance in plant health and survival: plant water relations, and plant energy relations. From 1985 to present, we have pursued a series of studies with two basic goals: 1) to determine if there are differences in these two systems which can be detected between stressed and unstressed plants; and 2) to gather information on the types of alterations which exist to permit efficient design of further investigations into these physiological systems.

Preliminary Investigation of Water Relations in High Elevation Red Spruce

One of the physiological systems of primary importance to a plant is its ability to maintain favorable moisture status. Many abiotic factors are known to cause plant decline by directly or indirectly altering a plant's internal water balance, and this is often the most important condition limiting plant growth (Kramer 1983). In summer 1985, we studied needle water potential in a high elevation red spruce stand on the eastern slope of Mt. Washington, New Hampshire. A total of 48 trees were selected for inclusion in this study, with 12 in each of 4 stress categories based on visual estimates of the percentage of dead foliage within each tree's live crown. Once a week, for 6 weeks, needle water potential was measured with a PMS Model 1001 pressure bomb in the grey light before dawn, or in the early afternoon (Donnelly and Shane 1985). During early morning hours water potential did not vary among stress categories (Figure 1). Lack of differences at this

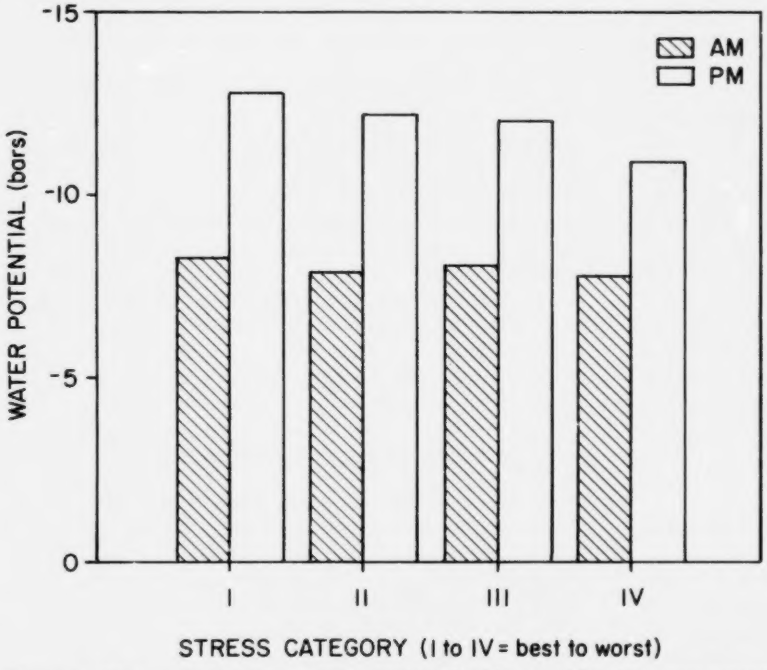

Figure 1.--Water potential of red spruce on Mt. Washington. Morning water potentials were significantly greater ($P \leq .05$) than afternoon values. Afternoon water potentials of Stress Category I trees were significantly lower than those for Category IV.

time implies a uniformity in the ability of these trees to ameliorate internal water deficits during an overnight period of recharge. At mid-day, however, trees in the highest stress category had the highest (least negative) water potentials. This finding has far-reaching implications since it indicates that healthier trees develop more negative water potentials, and therefore greater water deficits, than do less healthy trees. These differences may have arisen because of greater branch mortality than root mortality in declining spruce (and, thus, a higher root:shoot ratio); or, quite possibly, observed results may be due to differences in stomatal regulatory mechanisms among trees in different stress categories. If damaged trees shut their stomata at a critical water potential which is higher than the corresponding critical value for healthy trees, then the resulting afternoon water potentials would be higher in damaged plants, and this is the pattern we observed. It is very important, relative to these results, to recognize that while stomatal closure reduces rates of vapor loss, and is thus beneficial from the standpoint of water economy, it concomitantly eliminates CO_2 entrance and thus reduces the amount of photosynthetically-fixed energy compounds available to the plant.

Findings of the above study indicate the possible presence of differential aspects in water regulatory mechanisms between healthy and damaged spruce trees. Hypothetical extensions of these findings imply a potential link between water regulatory mechanisms and energy-capture systems via the stomata. We have taken this as preliminary support of our *a priori* notion that water and energy systems would be fruitful areas of study in red spruce.

Alterations in Energy Relations Caused by Stress in Red Spruce

In order to evaluate the impacts of stress on the energy-physiology of red spruce, we conducted two preliminary energy-related experiments in 1986: 1) effects of watering-solution pH and metal content on seedling net photosynthesis; and 2) an examination of fall foliar starch levels in naturally grown red spruce stands differing in their apparent vigor.

Effects of Watering-Solution pH and Metal Content on Seedling Net

Photosynthesis. In an attempt to identify factors responsible for observed differences in spectral properties of spruce foliage, NASA researchers at the Goddard Space Flight Center and the Jet Propulsion Laboratory initiated a greenhouse study at the University of Vermont to evaluate effects of solution pH and metal composition on spectral reflectance and laser-induced fluorescence. As part of this collaborative effort, we measured rates of net photosynthesis in a closed-cuvette gas exchange system on a subset of those seedlings.

In this sub-study, seedlings were watered with solutions containing 1 of 3 metals (Pb, Al, and Zn), each applied at 1 of 2 concentrations with the solution adjusted to either pH 3 or pH 4. In mid-August 1986, when they were approximately 17 months old, the above-ground portion of each seedling was inserted into a closed-cuvette gas exchange system (described in detail in Wilmot 1987), and rates of net photosynthesis were determined. The specific metal/pH treatments with their corresponding photosynthetic rates are presented in Table 1. Net photosyntheis did not differ among individual treatment means. However, when data were collapsed into two groups based solely on pH, we found that average net photosynthesis of pH 3 seedlings (2.42 μ mol $CO_2 \cdot m^{-2} \cdot s^{-1}$) was significantly lower than rates of pH 4 seedlings 3.06 μ mol $CO_2 \cdot m^{-2} \cdot s^{-1}$). Possible reasons for the lack of individual treatment differences are discussed by Donnelly and Shane (1987). The fact that alterations in photosynthetic rates were detectable based on solution pH differences suggests that detection of stress-related variations in photosynthesis are possible.

Table 1.--Net photosynthesis of red spruce seedlings which had been watered with a variety of metal/pH solutions. Each value represents the average of 3 replications (Donnelly and Shane 1987)

Watering Solutions			Net Photosynthesis [a]
Metal	Concentration (mg/l)	pH	μ mol $CO_2.m^{-2}.s^{-1}$
Al	0.003	3	2.67 ± .48
Al	0.003	4	2.97 ± .54
Al	3.000	3	2.82 ± .75
Al	3.000	4	2.52 ± .34
Cu	0.100	3	2.12 ± .40
Cu	0.100	4	2.94 ± .83
Cu	2.500	3	2.15 ± .51
Cu	2.500	4	2.91 ± .81
Zn	0.010	3	2.57 ± .40
Zn	0.010	4	3.08 ± .52
Zn	10.000	3	2.22 ± .32
Zn	10.000	4	3.93 ± .46

[a] Photosynthetic rates ± standard error

Carbohydrate Level in Red Spruce Foliage From Stands of Different Apparent Vigor. While carbohydrates are a direct result of photosynthesis, their accumulation and storage involve other energy-related processes. Analysis of carbohydrate levels, in addition to examination of photosynthetic rates, yields a more comprehensive picture of the energy systems of plants than can be provided by either parameter alone.

In mid-October 1986 we collected current-year foliage from trees in the previously described high elevation stand of Mt. Washington, NH and from a low-elevation, healthier stand in Granville, VT. Starch concentrations averaged 27.3 ± 7.9 mg/g in the low-elevation stands, but only 7.4 ± 2.3 mg/g in the high-elevation stand. Because of large tree-to-tree variability, these differences were not significant at $p = 0.10$. Thus, there was a tendency for high elevation spruce to contain less carbohydrate reserves. This tendency was apparent for the relatively healthy as well as the obviously declining spruce in this high-elevation stand.

Current Research

Based on the studies described above, several findings in concert have dictated our current research objectives. These findings are:

1. The severity of decline-symptoms in red spruce stands increases with elevation.
2. Water regulatory mechanisms may differ between spruce in highly stressed and healthy stands.
3. The nature of these alterations in water regulatory mechanisms implies the potential for alterations in energy-capture systems.
4. Differences in net photosynthetic rates can be detected based on alterations in watering solution chemistry.
5. Field study indicates that the concentration of stored foliar starch may differ between stressed and healthy spruce stands.

The fact that severity of decline increases with elevation suggests that: 1) genetic susceptibility increases with elevation in this species (i.e., there has been genetic differentiation along elevational gradients); 2) some environmental pressure(s), to which spruce is susceptible, increases with elevation; or 3) some combination of both (genetic x environmental interaction) exists. All other items listed above indicate that our *a priori* choices of energy and water systems as two physiological processes potentially involved in decline are appropriate, and warrant further investigation.

We are just beginning a 4-year field/laboratory investigation into energy and water relations of red spruce seedlings which will encompass findings from our previous research. This investigation, in a series of studies, will:

1. Produce photosynthetic and transpirational response surfaces.--Using our closed-cuvette system, we will measure net photosynthesis and transpiration at all 16 combinations of 4 light intensities and 4 temperatures to produce multi-dimensional response surfaces for these parameters. It has been suggested that red spruce is adapted to survive optimally at temperatures lower than those which presently exist (Williams 1986). Examination of response surfaces produced in this study will permit evaluation of hypotheses such as this.
2. Produce seasonal curves of carbohydrate (starch and sugar) concentrations and masses in needles (new and old), roots and stems.--These curves will allow us to test for differences, in both concentration and mass, of carbohydrates among various tissues and among points on the seasonal curves.
3. Determine the impact of a soil dry-down cycle on stem water potential, photosynthesis, and transpiration. We have modified our photosynthesis-transpiration cuvette to allow us to continuously monitor these parameters over extended periods of up to several months. In this study, these 3 parameters will be monitored during the time it takes a seedling to dry its rooting media from field capacity to the point which causes stomatal closure. These data will allow us to determine the role of water regulatory mechanisms and soil drying on normal plant functions.
4. Determine the nature and extent of xylem-embolism, and its possible role in the water economy of this species.

In an attempt to address the genetic versus environmental component in these studies, suggested by observed differences in stress at different elevations, 2 stands have been selected, 1 at high elevation, 1 at lower elevation, and the above experimental series will be performed on naturally-grown seedlings collected in each stand (to assess the environmental component), and on seedlings grown indoors in an optimal environment from seed collected in each stand (to address the genetic component). This study design is a very powerful one, encompassing knowledge gained from 4 years of preliminary study. We believe it will provide unique and valuable data applicable both from applied and basic perspectives, and should make significant contributions to other researchers working with red spruce.

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Design of an Open-Top Chamber to Study the Effects of Clouds and Ozone on Spruce Seedlings

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Abstract

A field chamber design is described for use in evaluating the effects of ozone and/or acidic cloudwater on the growth of red spruce at a high elevation site in the Appalachians. The experimental design of the study and the usefulness of development of the system is discussed.

Introduction

To successfully determine if pollutants contained within ambient air are detrimental to plant health, it is necessary to exclude ambient air from plants. Open top field chambers (Heagle et al., 1973; Mandl et al., 1973; and Kats et al., 1974) have proven to be useful in studies investigating the effects of ozone, sulfur dioxide, and other gaseous pollutants, alone or in combination. While chambers produce small changes in environmental conditions (Okszyk et al., 1986), they provide a realistic means for assessing air pollutant effects.

Adaptation of cylindrical chambers to assess the possible role of air pollutants in forest decline is a logical transfer of technology devleoped for studying pollution effects on agricultural crops. However, a number of unique problems exist in adapting open top chambers for studies involving the effects of air pollutants on trees especially if chambers are to be used at high elevation sites, where recent forest declines have been particularly evident in both Europe and North America (Johnson and Siccama, 1983; Zoettl and Huettl, 1986).

It is hypothesized that high elevation forest may experience greater damage because (1) greater exposure to atmospheric chemicals, particularly in the form of cloudwater, (2) elevated ozone concentrations that may be twice that of adjacent low elevation forests (Mohnen 1987). Above-cloudbase spruce forests may be enshrouded in clouds about one-half the time (Mohnen, 1987). This cloud water is highly acidic, mean acidity of pH 3.6 during the growing season, and may contain other pollutants, such as hydrogen peroxide, in sufficient concentration to cause injury to trees (Mohnen, 1987; Masuch et al., 1986). To evaluate the possible role of cloudwater in contributing to the decline of red spruce *(Picea rubens* Sarg.) in the field it then becomes necessary to be able to exclude cloud moisture, a capability which does not exist, nor was intended, for cylindrical chambers.

The objective of this paper is to (1) describe a chamber design that will be used to manipulate both ambient cloudwater and ozone deposition to red spruce seedlings at a high elevation forest and (2) describe the experimental design of a field study using these chambers.

Study Site

The chamber study will be located at Whitetop Mountain, Virginia, (1680 m) which is located on a southwest-northwest lying ridge of the Appalachian Mountains within the Jefferson National Forest. Chambers will be placed within a 0.5 ha fenced compound at the summit of the mountain that is the location of a Federal Aviation Administration (FAA) relay station. Since 1985 scientists from TVA's Air Quality Research Section have been involved in collecting meteorological and air/precipitation data at the site. Two distinct but complementary projects are funded in this research; the Forest Decline Project (FDP) co-funded by the U.S. Forest Service and congressional pass-through appropriations to TVA and the Mountain Cloud Chemistry Project (MCCP) supported by U.S. EPA and direct National Acid Precipitation Assessment Program (NAPAP) funds to TVA. Routine monitoring of gaseous (O_3, NOx, and SO_2), precipitation, and meteorological parameters are conducted continuously, while three intensive field studies (spring, summer, and autumn) focus on obtaining data on cloud water chemistry, rain event chemistry, cloud liquid water content, and liquid (cloud and rain water) and gaseous phase hydrogen peroxide concentrations. A complete listing of the parameter measured and the methodologies used are outlined by Mueller (1986).

General Chamber Design

Overall conceptual design of chambers follows that described by Kats et al., (1985). The chambers will consist of a 3.05 m diameter clear hemispherical fiberglass dome attached to a fiberglass base. Bases will be secured in selected locations by burying the base to a depth of 35 cm and backfilling with crushed stone on top of a flange completely encircling the base.

The dome portion of the chambers will be made from 8 fiberglass panels fabricated from resin material similar to that described by Mandl et al., (1973) to allow for at least 70 percent transmission of incident sunlight. The panels will be overlapped, fastened together by stainless steel bolts and a rubberized gasket will be placed on the upper surface of the base prior to fastening individual dome panels to the base. A removable doorway will be installed in one panel of each of the domes to provided access inside the chamber. The open top panel sections will be attached to a 1.22 m diameter metal stiffening ring by means of self tapping metal screws.

Ventilation of chambers will be provided by 0.75 kW centrifugal fan with a 0.31 m diameter backward curved blade capable of providing $30m^3 min^{-1}$. Air will enter the base through 21 cm diameter sheet metal pipe attached to the fan. Six 1.55 m sections of polyethylene plastic connected by sheet metal elbows and a T-fitting will form a circular air distribution system within the chamber base. Each 1.55 m section of duct will have 2 rows of 1.20 cm holes spaced 3.81 cm apart. Air flow within ducts will

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be maintained to provide approximately three air changes per minute.

Individual Chamber Treatments

Three chamber treatments are planned: (1) exclusion of clouds and ozone, (2) exposure to ambient ozone with clouds excluded, (3) exposure to both ambient clouds and ozone. A fourth treatment will also be included to assess the "chamber effect" by maintaining seedlings in unenclosed plots. Each treatment will be replicated three times, each replicate containing 20 seedlings that have been transplanted from an adjacent spruce stand into 10 L plastic plot containing native O horizon soil material from the stand where seedlings were obtained. Seedlings will be grown in chambers for 2 years; however, chambers will not be operated in the winter months.

To achieve exposure to both ambient clouds and ozone (treatment 3), a retractable chamber will be used (Figure 1). The dome portion of these chambers will be hydraulically lifted when clouds are present on the site. A voltage signal from a reflectometer will be used to automatically sense presence or absence of clouds and signal the hydraulic pump to either raise or lower the domes. The correlation of reflectometer data and actual cloud occurrence as measured by on site observers at the Whitetop station have shown excellent agreement (Mueller et al 1986). When retractable domes are in the closed position (no clouds present), ambient air will be supplied to the chambers by means of a centrifugal fan. Fans will automatically be shut off or on when the dome portion of the chamber raised or lowered, respectively.

A single hydraulic power unit consisting of a pump, a 1.1 kW motor, control valves, adjustable relief valves, and double pilot check valves will be used to operate the hydraulic cylinders in each of the three retractable chambers. Cylinders will be secured to a concrete pillar located in the center of the base. Attachment at the top will be to base plate mounted on 4 struts in the center of a 1.22 m stiffening ring. Seven stainless steel guide supports will be attached to the base of the chamber at points corresponding to the midpoint of individual panels (Fig. 1). The eighth support is purposely omitted since that panel is equipped with a doorway to allow access into the chamber.

Design of the chambers used in the other two treatments will be similar to that described for the retractable chamber described above, except that the dome section is permanently fixed rather than retractable, thus eliminating the need for the hydraulic system or the guide supports. To exclude ambient clouds in treatments 1 (exclusion of cloud and ozone) and 2 (exposure to ambient ozone with clouds excluded), a B-Gon mist Eliminator manufactured by Kirme Incorporated (Perrine, FL) will be fitted into a sheet metal housing connected to the centrifugal fan inlet. A prototype test of the effectiveness of these filters in removing cloud droplets from actual air masses indicated satisfactory removal of cloud moisture. Removal of ozone (treatment 1) will be accomplished by placement of charcoal filters downstream from the exist duct of the fan. The design and construction of the ozone filtration system will be identical to that described by Jones et al., (1987). Because of differences in static pressure in the overall air delivery system due to placement of filters in the two chamber treatments, adjustments in operational parameters of fans will be made to provide equal ventilation to all chamber treatments.

Ozone concentrations within chambers will be monitored continuously through stainless steel heat traced lines. One ozone monitor and a data logger program enabling sequencing of sampling from individual chambers will be used to sample ozone in each chamber over three minute intervals to produce one-hour mean values. Additionally, one chamber from each of the 3 treatments will be equipped with a Rotronic temperature and relative humidity (RH) probe set-up to collect one minute temperature and RH data which will also be averaged to produce hourly estimates. Monitoring of ambient ozone, temperature and RH will be conducted by TVA scientists involved in the MCCP project at Whitetop Mountain.

Characterization of the liquid water content (LWC) of air within chambers will be done on an event basis. The procedure used to measure LWC consists of collecting a sample of cloud droplets on a polypropylene mesh filter from a metered volume of air and calculating concentration of water in g/m^3. These measurements will customarily correspond to the same 3 week period that intensive field sampling is conducted at the Whitetop station, thereby allowing for comparisons between ambient and chamber environments.

Measurement of Seedling Growth Response

Throughout the growing season periodic evaluation of the physiological response of seedlings will be determined by measuring photosynthetic rates, stomatal conductance, and needle water potential. Periodic event sampling of cloud droplet interception by seedling foliage will also be made during the growing season. Samples will be analyzed by ion chromotography for NO_3, SO_4^{2-} Cl , H+ NH_4+, K+, Na+, Ca^2+, MG^2+. A subset of seedlings will be destructively harvested at the end of each growing season to determine root and shoot biomass accumulation and tissue nutrient concentrations. Additional cooperative studies are also planned to investigate treatment effects on root hydraulic conductivity and weathering of epicuticular needle waxes. It is hoped that other cooperative studies may be developed depending on the constraints imposed by time and budget.

Conclusion

This paper has described the design and construction of a field chamber to be used in evaluating the effects of cloud moisture and ozone on the growth of red spruce. Both of these factors have been implicated as contributing to growth declines and mortality in high elevation coniferous forests. Therefore,

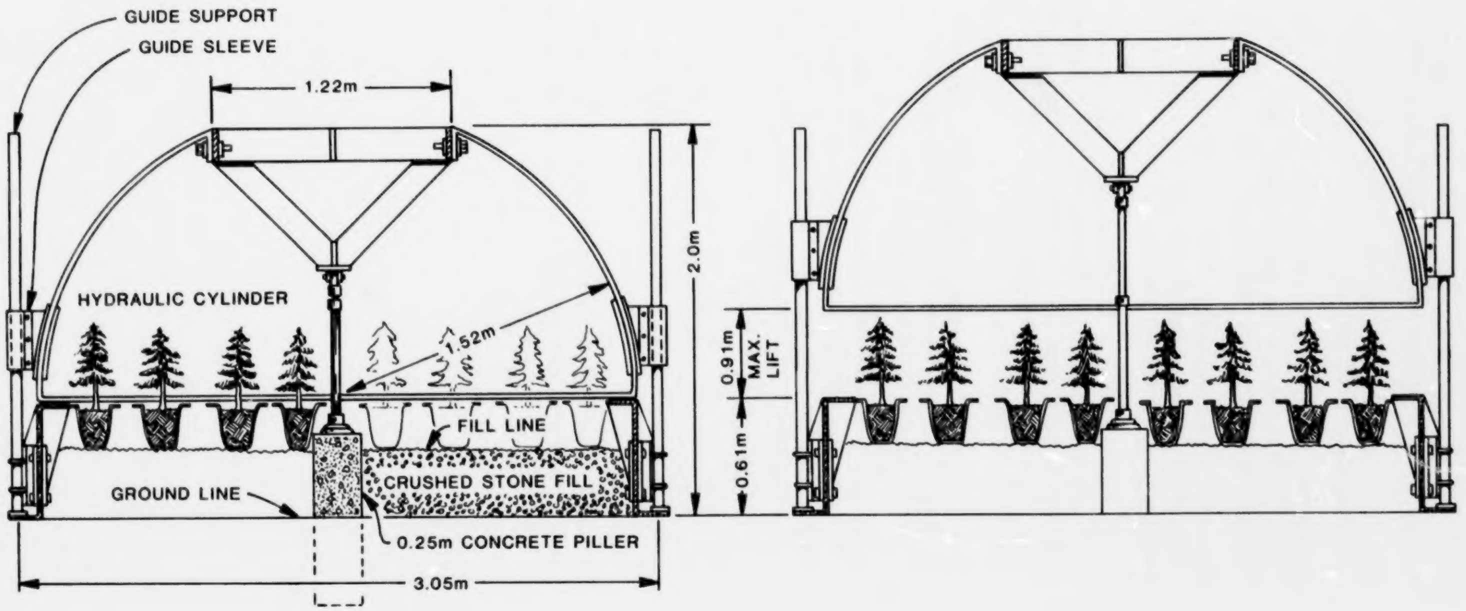
GUIDE SUPPORT
GUIDE SLEEVE
1.22m
HYDRAULIC CYLINDER
1.52m
2.0m
0.91m
MAX. LIFT
0.61m
FILL LINE
CRUSHED STONE FILL
GROUND LINE
0.25m CONCRETE PILLER
3.05m

Figure 1.--Retractable cloud exclusion chamber.

development of a chamber system that is capable of selectively excluding these pollutants under actual field conditions will be one of the most meaningful ways to determine the actual impact of these alleged pollutants on tree growth.

The fact that this project is collocated at a MCCP site will greatly facilitate interpretation of experimental chamber results, since a complete database of meteorological and air/precipitation chemistry will be available to describe environmental stresses that could potentially affect growth of red spruce. This study will be of particular value in integrating laboratory and field fumigation studies within the Spruce-Fir Research Cooperative on the effects of these pollutants on carbon allocation and physiological processes. This research will provide measures of response to actual pollution levels in the natural environment which can be directly compared to results obtained from studies simulating ozone and/or acidic cloudwater deposition. Additionally, the physiological response data gathered in this project will be compared to *in situ* measures of carbon supply/allocation made on both seedlings and mature trees along an elevation gradient of the Great Smoky Mountains National Park (McLaughlin et al., 1986). These data will be especially important since they provide a means of linking plant response among native field grown seedlings, experimental seedlings, and mature trees.

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Design and Testing of a Field Branch Enclosure for the Exclusion of Atmospheric Components

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Abstract

An exclusion system was developed to examine the effect of ambient atmospheric components on growth and winter survival of red spruce tissues. Branches were enclosed in plastic chambers designed to withstand the rigors of the montane environment, and were maintained for one growing season. Structural performance was satisfactory, and with some modifications, environmental conditions within the chambers can be made to track the ambient conditions. Several biological parameters were followed through the season, and some changes were noted in the filtered treatment.

Introduction

Measuring the response of mature forest tree species to alterations in their environment is a difficult task. From the standpoint of full-scale productivity and growth measurements, it would be desirable to enclose entire trees within chambers to regulate their environment. Such a device would allow studies of the effects of exclusion or addition of airbone materials, such as water vapor, aerosol chemicals and gases. Incorporation of entire trees within enclosures may, however, be economically and technically infeasible for field installations.

An alternative is to enclose a portion of the tree. Although this may not be fully satisfactory for determining whole tree growth response, it is potentially useful for making measurements of physiological and biochemical responses of the photosynthetic tissues. Enclosing a branch, rather than a small portion of the foliage such as a twig, allows manipulation of the environment of many age classes of needles. In addition, several chambers may be placed on a single tree, permitting replication without between-tree effects.

We wish to assess a number of physiological parameters related to growth and cold tolerance in red spruce (*Picea rubens* Sarg.), as a function of the chemistry of the atmospheric environment at high elevation on Whiteface Mountain, New York. Red spruce is suffering unusual mortality in high elevation sites in the Adirondack mountains, possibly as a result of increased winter damage (Friedland, et al., 1984; Johnson, et al., 1986, 1987). One hypothesis is that airbone materials are affecting the growth and/or winter resistance of this species. We have begun testing this hypothesis by constructing branch chambers designed to exclude aerosol and oxidative components, in order to determine if in situ exclusion of ambient cloudwater and gaseous compounds has any effect on the physiology or winter hardiness of needles and twigs of mature spruce trees.

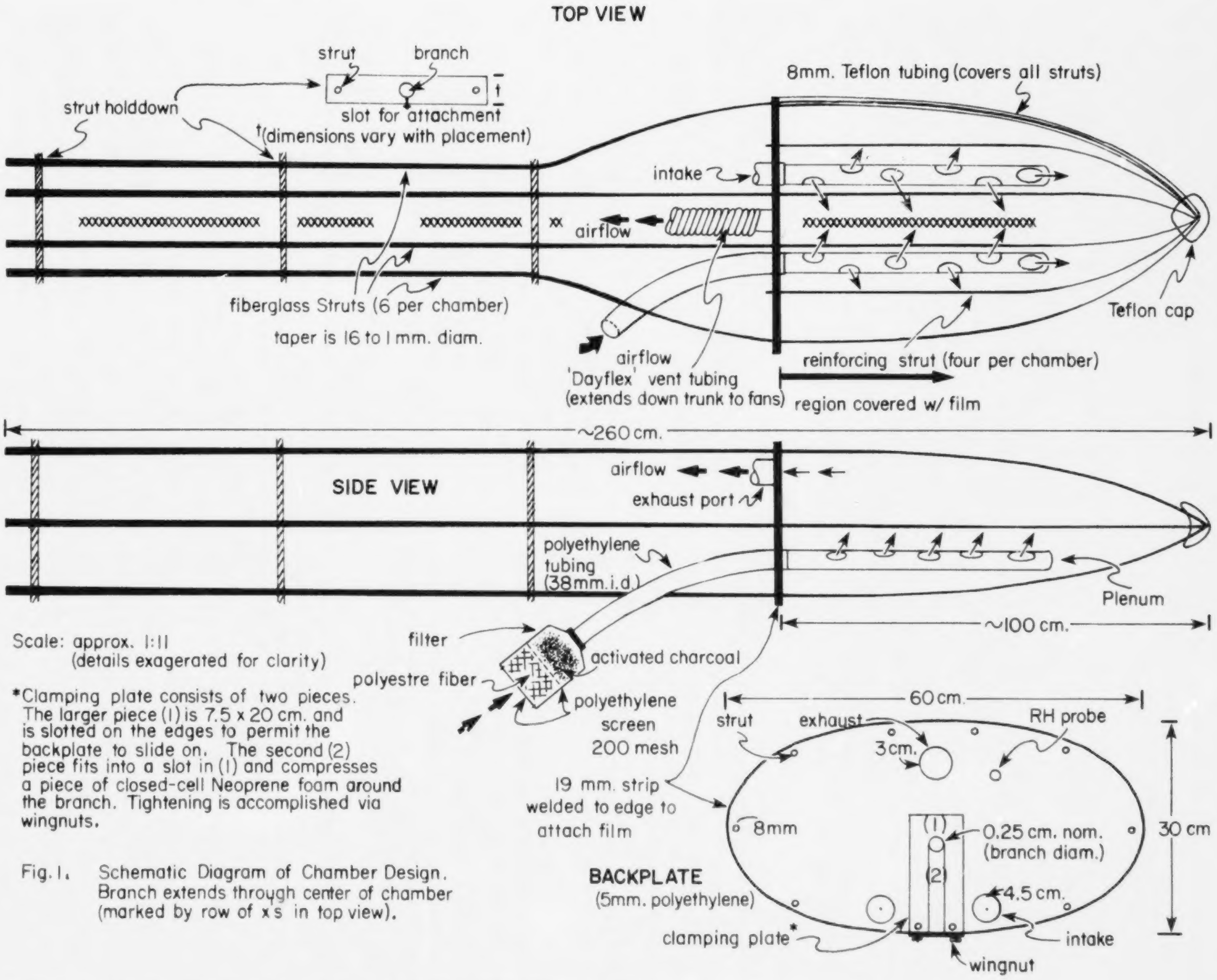
Design of the chambers was determined largely by the site under study. For the purposes of an earlier study, a plot was located in the spruce-fir zone, near the top of an exposed ridge on Whiteface Mt., at 1170 m a.s.l. It is about one kilometer above the access road for the mountain. This plot contains a number of spruce showing extensive crown damage, as well a few trees which appear normal. The site is inundated in cloud about one third of the time, and is subject to high winds and severe thunderstorms. Park regulations do not permit the construction of permanent structures, barring the installation of towers to access the branches. Onsite monitoring of ambient air quality prohibits the use of hydrocarbon-fired electrical generators.

Design

With these limitations, it became necessary to build chambers which fulfilled a particular set of requirements. These included flexibility and low air resistance, to withstand winds; simple installation from within the tree under study; and battery powered operation.

Chamber shape was chosen to conform to the branch shape and to minimize horizontal profile. Branches are flattened, and tapered at the tip, leading to a somewhat triangular shape. As a result, the shape chosen was half of a flattened ovoid. Due to technical considerations, only the distal meter of the branch was enclosed. Chamber supports were attached primarily to the branch under study, in order to permit natural movement of the branch during storms. Materials were chosen for strength, flexibility and light weight, minimizing both deflection of the branch, and branch oscillation during high winds.

In designing the air flow system for the chambers, two options were considered, forced air and drawn air. Forced air (positive pressure) systems have certain advantages. In these systems, leaks are less important, as is the resistance of the filters. They also allow for simpler construction, as part of the chamber film support is provided by the positive pressure. However, as the experimental goal was exclusion of atmospheric components, drawn air (negative pressure) was used. In this case, the control for chamber effects was an unfiltered chamber, into which it was necessary to draw clouds. Use of a forced air system would force clouds through the fan, thus altering the characteristics of the aerosol. Placing the fan in the air path after the chamber allows a better approximation of a normal cloud inside the chamber. This system does have drawbacks, however. No leaks can be allowed, or unfiltered air can enter. The pressure drop across the filter is the biggest problem, causing negative pressures within the chamber. As a result, additional ribs are required for support, to prevent the film from collapsing inward.


TOP VIEW
strut
branch
8mm. Teflon tubing (covers all struts)
strut holddown
slot for attachment
†(dimensions vary with placement)
t
intake
airflow
fiberglass Struts (6 per chamber)
taper is 16 to 1 mm. diam.
airflow
'Dayflex' vent tubing
(extends down trunk to fans)
reinforcing strut (four per chamber)
region covered w/ film
Teflon cap
~260 cm.
SIDE VIEW
airflow
exhaust port
polyethylene
tubing
(38mm.i.d.)
Plenum
~100 cm.
filter
activated charcoal
polyestre fiber
polyethylene
screen
200 mesh
19 mm. strip
welded to edge to
attach film
60 cm.
strut
exhaust
3cm.
RH probe
8mm
(1)
(2)
0.25 cm. nom.
(branch diam.)
30 cm
4.5 cm.
BACKPLATE
(5mm. polyethylene)
clamping plate*
intake
wingnut

Scale: approx. 1:11
(details exagerated for clarity)

*Clamping plate consists of two pieces. The larger piece (1) is 7.5 x 20 cm. and is slotted on the edges to permit the backplate to slide on. The second (2) piece fits into a slot in (1) and compresses a piece of closed-cell Neoprene foam around the branch. Tightening is accomplished via wingnuts.

Fig. 1. Schematic Diagram of Chamber Design. Branch extends through center of chamber (marked by row of x's in top view).

Figure 1.--Schematic diagram of chamber design. Branch extends through center of chamber (marked by row of x's in top view).

Construction

A schematic drawing of the chamber is shown in figure 1. Supporting struts were made from tapered hollow fiberglass tubes (fly rod blanks), which met the above requirements perfectly. Strut holddowns were made of high density polyethylene, as was the backplate of the chamber. The backplate supported the various monitoring instrument as well as the plastic film which made up the enclosure. The covering used was Propafilm C, a polyvinyl chloride coated polyester film having low permeability to gases.

Final dimensions varied somewhat, due to irregularities in branch shape. The backplates were 30 cm by 60 cm, and the depth was generally 90 cm; this varied with branch length. This produced a final volume of about 85 liters.

Exclusion of airborne materials was accomplished by drawing air through two-stage filters containing polyester fibre and activated charcoal. The former served to remove aerosols, and the latter to eliminate oxidant gases. These filters were built into 2-liter Nalgene bottles, and connected to the chamber backplate through polyethylene tubing (38 mm i.d.). Two such assemblies were installed on each filtered chamber. The control chambers were fitted with short sections of tubing open to the atmosphere below the branch. Air distribution within the chambers was facilitated through the use of plenums made of Propafilm.

Installation was performed from within the tree under study, using safety ropes and Tyrolean traverses to position the installer. Pieces were precut, and designed to slide together. All supports, tubing and wiring were installed using plastic cable ties, permitting quick attachment. The ends of the struts were tied together using nylon filament, and capped with small Teflon cones. The plastic film was installed using double-sided polyester tape.

The electrical system was quite simple, consisting of battery-powered fans. Batteries were lead-acid, deep cycle marine units, of 35 or 80 ampere-hour discharge capacity. Batteries were changed daily, and were charged off-site. The fans were 24 volt, 200 cfm axial vane types operated at 12 volts to reduce power consumption and air displacement. Two fans were installed at each location, with the second operating as a back-up fan in case of failure. The latter fan was activated by an electronic airflow sensor in the airstream. Total power consumption per station was 24 watts. The fans were built into boxes placed at the base of the tree, permitting simple service. This necessitated long tubes extending up the trunk, to connect the chamber. These were made with Dayflex (Dayton Rubber Co., Dayton, OH) vent tubing five cm. in diameter. Air resistance of the tubes reduced the airflow at the chamber exhaust to about 570 $1m^{-1}$. This still resulted in a high turnover rate of 5-7 exchanges per minute.

Monitoring

Three principal enviromental parameters were measured inside the chambers; photosynthetically active radiation (PAR), relative humidity (RH) and temperature. The values were recorded using Li-Cor LI-1000 dataloggers. Hourly mean values for relative humidity were determined using independently-powered Vaisala probes (HMP 31 UT) mounted within the chamber, near the exhaust port. A single probe was mounted externally to one chamber to provide ambient humidity. Solar input was recorded as integrated hourly totals from the output of Li-Cor PAR sensors (type 190SA). Sensors were placed midway down the portion of the branch within the chamber. In some cases this led to higher PAR values internally, apparently due to reflection from the chamber backplate. Temperature was measured with Omega type T copper-Constantan thermocouples (24 ga.) and recorded as hourly means for ambient air (5 cm. above needle level) and needle surface (via an appressed junction). Mean hourly total solar input was estimated using a Li-Cor 200SA pyranometer. Hourly minima and maxima were also recorded for all variables.

Experimental Design

Biological response to filtered air was attempted for three trees. These tree were mature, canopy-dominant trees, 95-125 yrs. old at breast height. Two trees were determined to be in a declining state, having lost more than 50% of the needles in the crown. The third tree was visibly asymptomatic. Three branches on each tree, at the same whorl and similarly oriented, were used for sampling. One branch was fitted with environmental monitoring sensors, and served as the within-tree control. Chambers were placed on the two remaining branches. One chamber drew ambient air as the chamber control, and the other drew filtered air, as the treatment. Branches were selected at the tenth through thirteenth whorl, and were 2.5-3 m long. Branches were chosen to be above the neighboring canopies, and fully exposed to the atmosphere. Proximally, within the crown, a third or more of the branch was devoid of foliage. As a result, the one-meter enclosure contained nearly all of the foliage on the branches on declining trees, and about one-third of that on the asymptomatic tree. Samples were collected at ten day intervals to assay for pigment composition, protein, and carbohydrate content. Immediately upon collection, samples were frozen in liquid nitrogen and transported to the lab on dry ice, where they were ground in liquid N_2 prior to analysis. Chlorophyll was evaluated according to Arnon (1949); carotene by the method of Holm (1954). Protein was measured using the Bio-Rad Protein Assy (modified Bradford assy). Carbohydrates have not been determined at this time.

Results and Discussion

Mechanically, the chamber performed quite well. The few breakages which occured were all due to failure of one of the fibreglass poles during rainstorms. This problem was eliminated in later designs, in which the poles are inserted into Teflon tubes. Chamber movements were watched during storms. The chambered branches did not move as freely as open branches, although this did not appear to be a problem. The chambers were deflected downward during rainstorms due to the weight of the falling water.

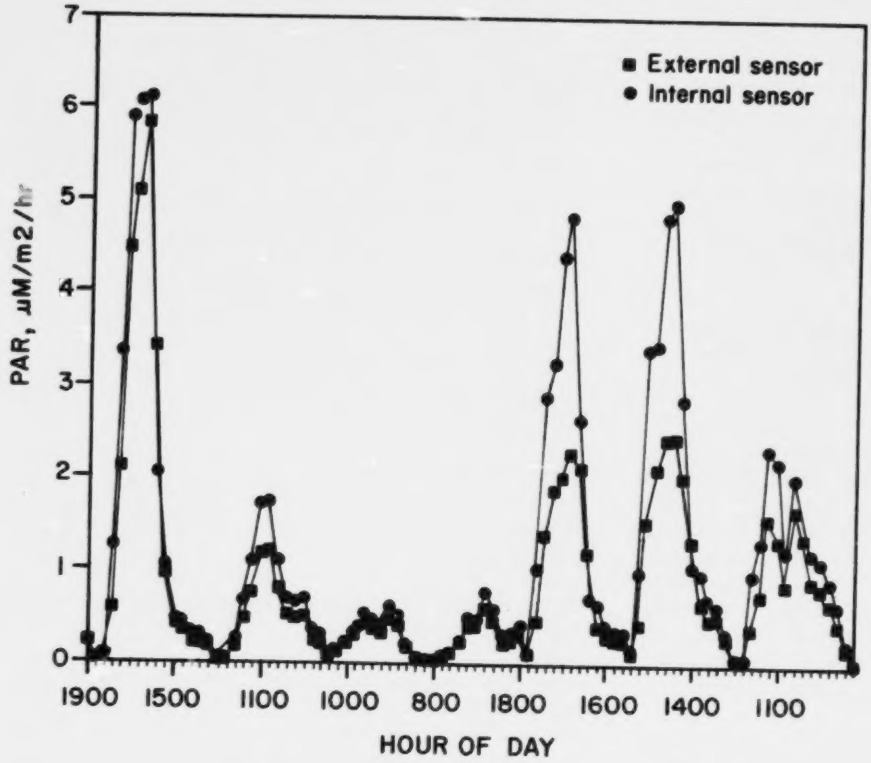


Figure 2.--Integrated hourly PAR values. Dates shown 8/21-8/26.

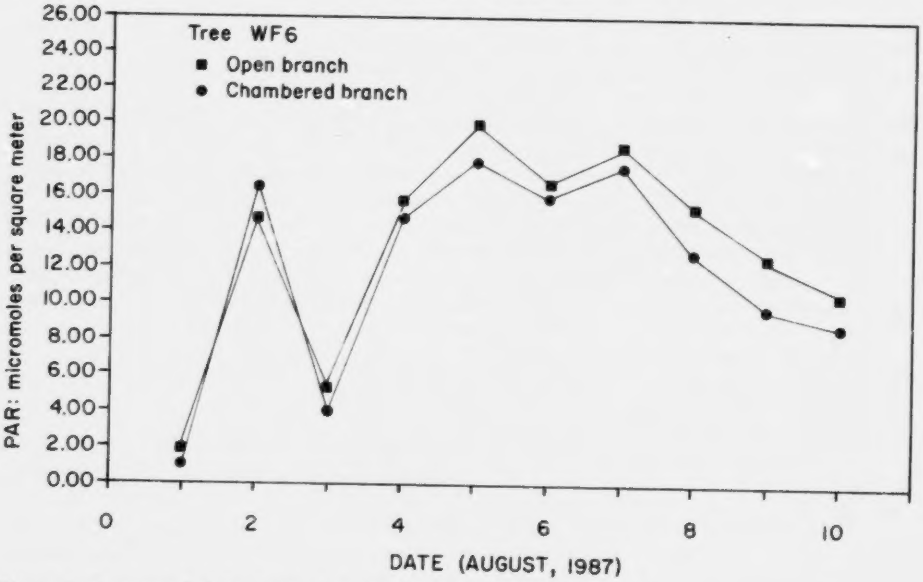


Figure 3.--Integrated daily PAR. For dates 8/1-8/10. Values represent total daily input.

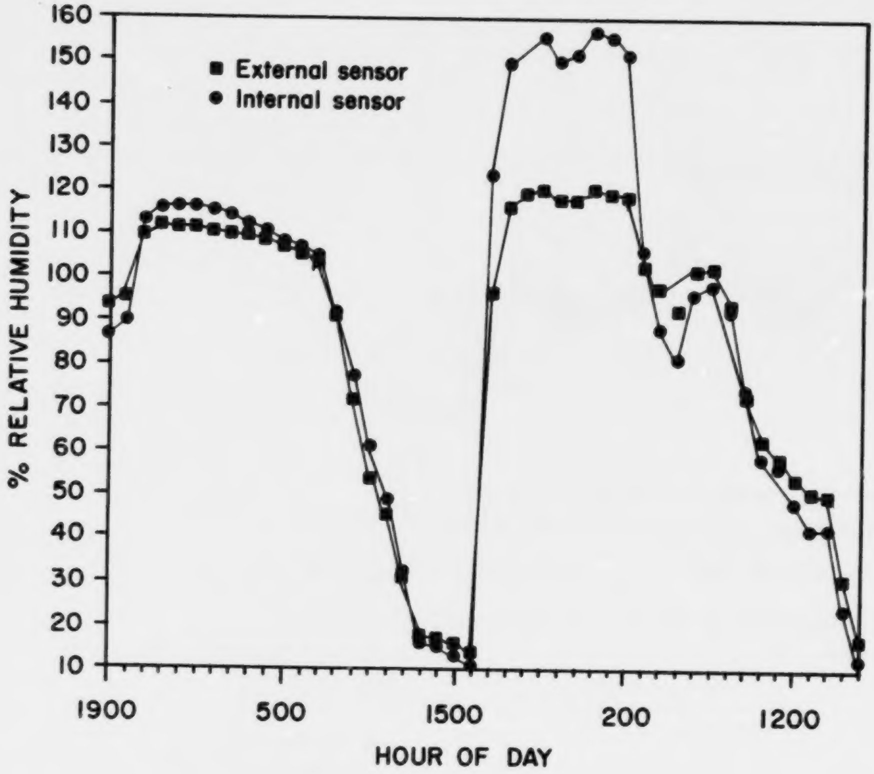


Figure 4.--Hourly average humidity values. Values shown for dates 8/21-8/23. Values above 100% RH result from the presence of clouds.

The chambers performed fairly well in maintaining a uniform environment consistent with the external conditions. The light environment was comparable between interior and adjacent, exterior sensors (fig. 2). The greater internal value occured as a result of reflection from the backplate. Daily integrated solar input was similar between open and chambered branches (fig. 3). Humidity was also similar (fig. 4). Values above 100% RH occured when clouds or rain were present. These sensors proved to be the most difficult to maintain, and some data was lost due to battery expiration and calibration drifting. Temperature performance was less satisfactory. Adjacent sensors show a temperature rise of as much as 4 C (fig. 5). The sharp peak at 1300 h on the second day occured as a result of the failure of one of the fans, permitting a rise of some thirteen degrees on an overcast day. Figure 6 shows values for both chamber and the open branch on two sunny and one overcast day. Chambers were significantly warmer than the ambient air. This may be improved by increasing the airflow or by pre-cooling the air in some manner.

The principal difficulty was in maintaining airflow for the entire summer. Fan and battery failures permitted chamber temperatures to reach a lethal level in two cases. This occured quite rapidly, within two to four hours above 37 C, killing 20-30% of the foliage in the chambers in declining trees. These rises occured during bright, sunny days with ambient temperatures of 29-32 C.

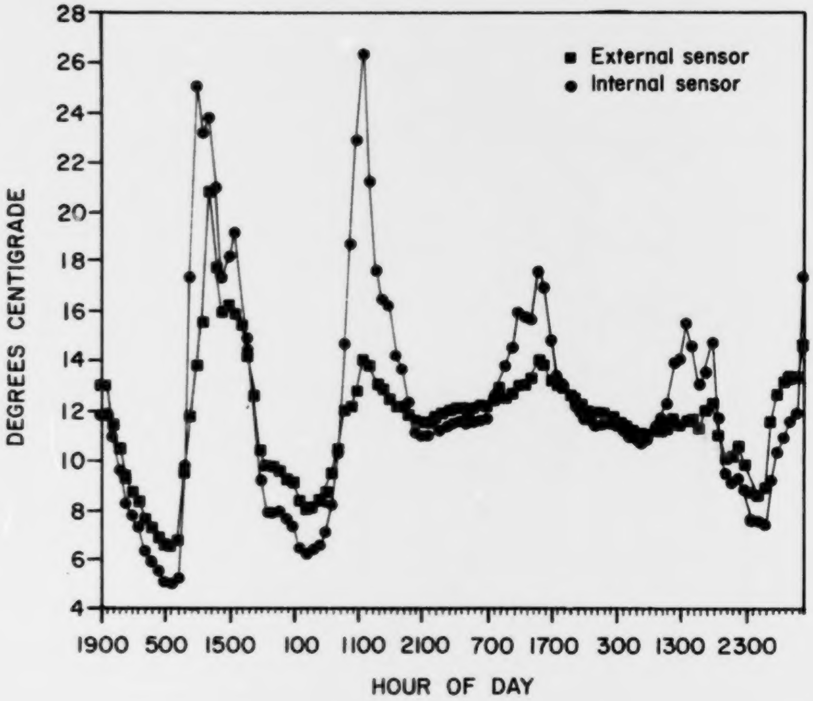


Figure 5.--Hourly average temperatures. Dates shown for 8/21-8/26. Sensors mounted on same chamber, internally and externally.

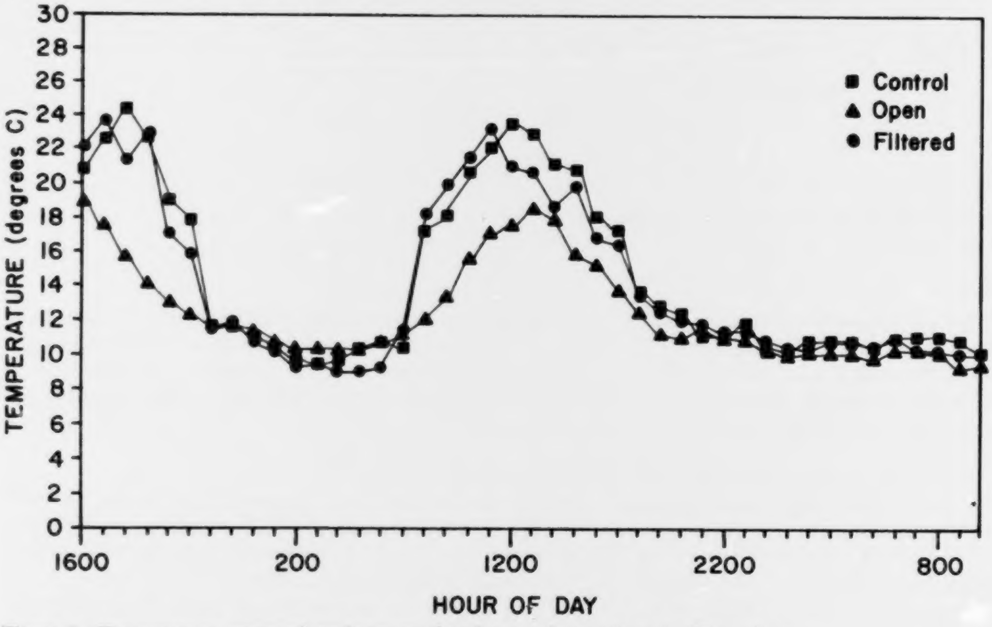


Figure 6.--Temperatures comparison between chambers and open branch. Three days shown, 8/8-8/11.

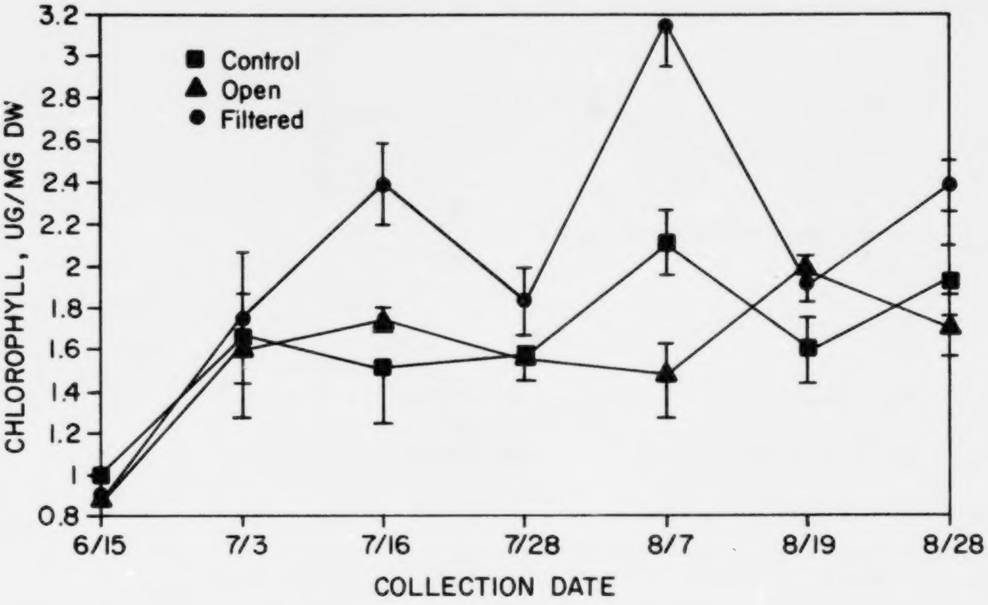


Figure 7.--Chlorophyll content for 1987 needles. Vertical bars represent ± s.d.

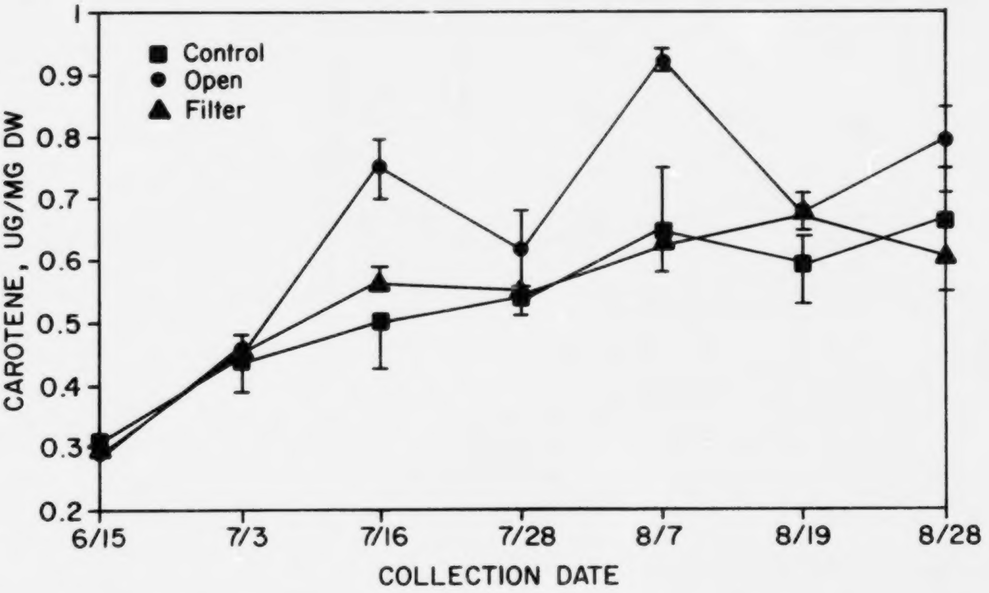


Figure 8.--Total carotenes for 1987 needles. Determined at 440 nm. Vertical bars represent ± s.d.

On the asymptomatic tree, the chambers operated without major failure for eight weeks, and some biological responses to filtered air were observed. Treated needles were visibly greener (fig. 7), and contained higher levels of carotenes (fig. 8). The decrease in pigments on 8/19 coincides with and is likely due to a temporary cessation of airflow, and consequent overheating. Partial recovery was evident by 8/28. Similar relationships held for fresh and dry weight (figs. 9, 10).

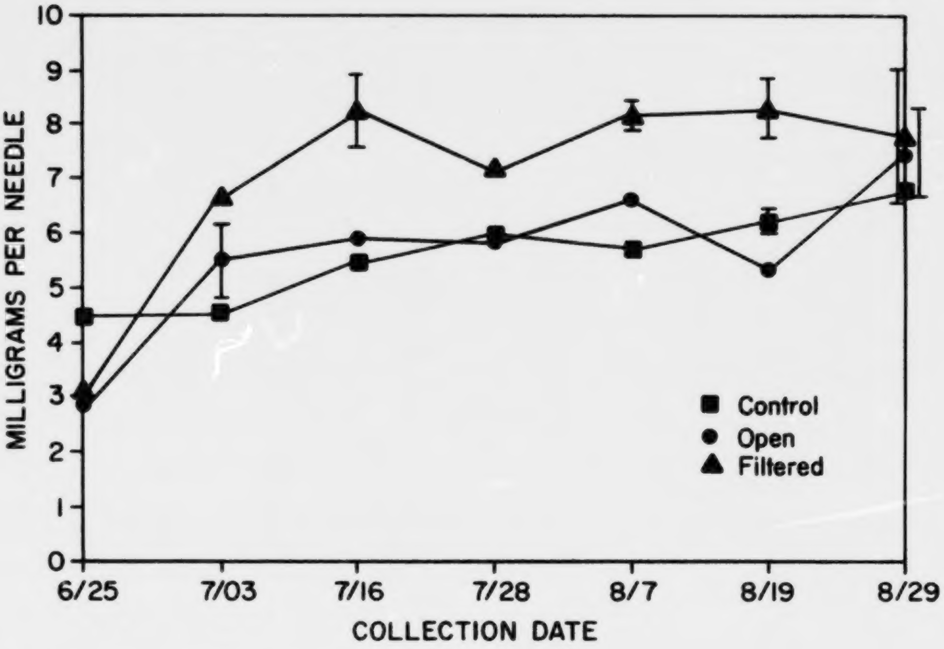


Figure 9.--Needles fresh weights. Vertical bars represent ± s.d.

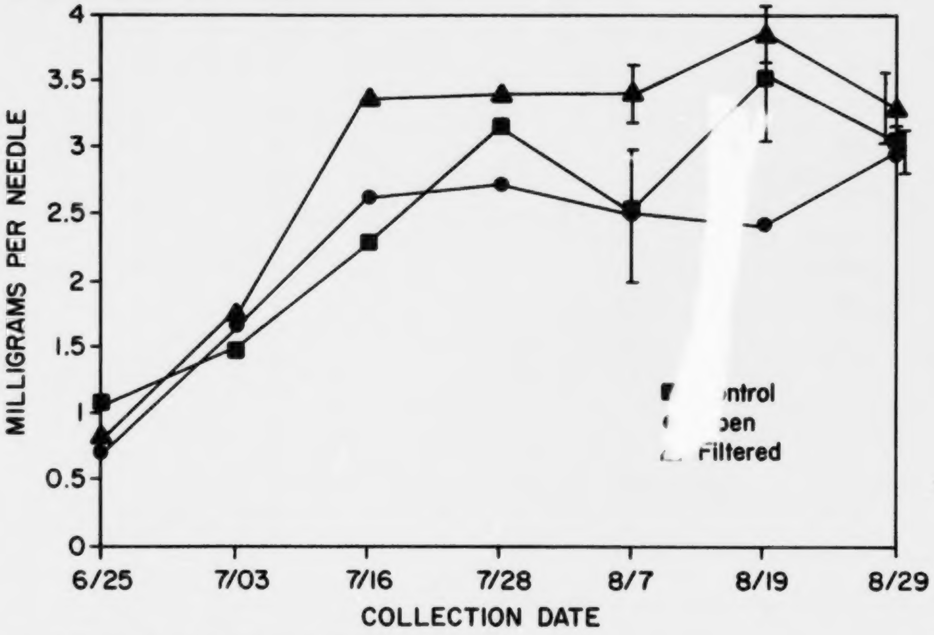


Figure 10.--Needle dry weights. Vertical bars represent ± s.d.

In conclusion, we felt that this design for a completely enclosed branch chamber system is useful for examining plant responses to atmospheric conditions. Several modifications have been incorporated into the design of future chambers. These include: 1. the use of PFA polyfluorocarbon materials for all internal surfaces of the chamber. 2. use of PFA tubes for the cage supporting the film, through which the fibreglass support rods are then inserted, improving chemical inertness and preventing breakage, as well as reducing assembly time. 3. Improved air mixing systems within the chambers, to aid in temperature control. 4. use of a more reliable fan and power system. These modifications should permit us to operate these chambers within the environmental guidelines set up for NCLAN-type open chambers. However, it may be necessary to define parameters specifically for enclosed systems of this type. In particular, measurements of both environmental and physiological conditions will need to be defined for comparability between experimental systems, since specific applications of branch chambers may dictate different technological solutions.

Acknowledgments

We wish to thank Roger Cox, of ICI Americas for donating the Propafilm; J.C. MacFarlane and D. Tingey of the U.S. E.P.A., Corvallis, for helpful technical suggestions; and J. Battles and his forest survey crews for carrying batteries up the mountainside. This research was supported by a grant from the Andrew W. Mellon Foundation.

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Long-term Effects of Air Pollutants on Spruce and Fir in Open-Top Chambers

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Abstract

*In early 1983, model ecosystems in open-top chambers were designed to investigate long-term effects of air pollutants (ozone and/or sulphur dioxide; simulated acidic rain) at near ambient concentrations on mineral cycling, physiology and biochemistry of young spruce (**Picea abies** (L.) Karst.) and fir (**Abies alba** Mill). The chambers contain soil lysimeters and are protected against the intrusion of ambient rain. The soil in the lysimeters originates from an older stand of beech-fir-spruce in the northern Black Forest. In the course of exposure, alterations in mineral cycling, tree physiology and metabolic plant processes caused by sulphur dioxide and ozone could be observed. The combination of both pollutants often resulted in responses that were greater than the single effects. The fumigation experiments in open-top chambers with soil lysimeters are a central part of an experimental chain, integrating similar measurements in different forest stands, as well as in open-top chambers placed around 15 year old spruce in a diseased forest area.*

Introduction

Different methodological approaches have been used to investigate the causes of the current forest decline in Europe. With respect to the direct effects of air pollutants on above-ground plant parts, fumigations of young trees or parts of these trees with the phytotoxic gases SO_2, NO_2 and O_3, simulated acid rain treatments or comparisons of tree growth in filtered and non-filtered air have been carried out (Keller 1984; Roberts 1984; Guderian et al. 1985; Skeffington and Roberts 1985; Krause et al. 1985; Payer et al. 1986).

However, in many of these investigations short term, high concentration pollutant treatments under non-realistic environmental and artificial growth conditions of the trees were used. While these studies are useful for answering questions about the general mechanism of a pollutant attack and for testing a specific hypothesis, their usefulness for the interpretation of long-term low-level effects of air pollutants on forest ecosystems is limited.

To overcome some of the above mentioned drawbacks, model ecosystems consisting of young spruce, fir and beech trees (including a natural herb layer) were installed in open-top chambers at the University of Hohenheim/FRG in 1983 to investigate the long-term effects of low concentration of SO_2 and O_3 (singly or in combination) and of acidic rain. Over an almost five-year period, the trees, which were grown in soil lysimeters on natural soil from a regional forest stand, were continuously exposed to the pollutants. Mineral cycling and a variety of physiological, biochemical and anatomical parameters of all three tree species were investigated at regular intervals. To our knowledge this experiment in open-top chambers is the first multidisciplinary approach to study air pollutant effects in the canopy and in the soil simultaneously over several years in model ecosystems with forest trees. It is also a central part of an experimental chain, integrating similar field measurements in different forest stands and in open-top chambers with filtered and non filtered air placed around 15-year old Norway spruce in a partially damaged forest in South Germany.

Materials and Methods

Exposure Chambers and Experimental Design

The experiments were conducted in open-top chambers at Stuttgart-Hohenheim/FRG. In addition to the regular open-top chamber design (Mandl et al. 1973; Heagle et al. 1973) some modifications required in the consideration of the specific situation, i.e. working with groups of young tree seedlings, have been made. Each chamber (3 m diameter; 4 m total height) is built upon lysimeters (1 m deep) and is protected from ambient rain by a rain shelter 1 m above the open-top (Figure 1). Air is drawn by a blower through a filter system (particulate filters, activated charcoal) and enters the chambers through tubes on the ground, dividing the ground area into three segments. A drawback in this system is that air moves unnaturally from the ground upwards, but this is thought to be better than air moving from the side, with a clear gradient to the center as a result of canopy resistance. Air flow into the chambers was approximately 2,200 $m^3 h^{-1}$ (about 1.5 air changes per minute).

Climatic conditions are measured continuously inside and outside the chambers: air temperature with Pt-100 elements, humidity with the aspirated psychrometer, global radiation and reflected radiation (0.3-60 μm) with radiation balance transmitters, PAR radiation with Quantum sensors, outside wind velocity with a cup anemometer, inside wind velocity with a thermo-anemometer. Piche evaporimeters are installed in each chamber recording values twice a week and sensors are used to determine the soil moisture. Occasionally the soil and leaf temperature are measured manually. Because tree seedlings (especially fir) in their natural environment are adapted to restricted incidence of light and low windspeeds, shade cloth was stretched between the rain shelter and the top of the chamber. Because of the reduced light intensity within the chamber, the rise in temperature is also reduced. However, a 1° C higher mean temperature within the chamber compared to the outside and up to 4° C higher temperature in full sunlight are important.

Treatments consist of 6 chambers receiving charcoal-filtered air (CF, in 2 chambers) and CF to which either O_3, SO_2 or $SO_2 + O_3$ are added. In those treatments simulated acidic rain of pH 4.0 is used. In one chamber the trees are exposed to CF and simulated rain at pH 5.0.

Pollutant Dispensing and Monitoring

SO_2 is applied continuously from a pressure bomb (99% SO_2) and gas flow is regulated by a constricted tube pump. Ozone is produced by an ozone generator using pure oxygen; O_3 flow is regulated by a mass flow controller. Both gases are delivered into the stream of purified air entering the chamber through a 6 mm Teflon pipe. Air from the chambers is sampled through Teflon tubes (∅ 6 mm). SO_2 concentrations are monitored using a Beckmann 953 SO_2 analyzer, and O_3 and NO_x concentrations are monitored with Monitor Labs analyzers (Monitor Lab INC, San Diego, USA, model 8810 for O_3, model 8840 for NO_x).

In 1984 the SO_2 exposures consisted of a concentration of about 70 $\mu g/m^3$ (winter: 80-100 $\mu g/m^3$; summer: 30-50 $\mu g/m^3$ (Figure 2). In 1985 the SO_2 concentration was reduced to average values of roughly 30 $\mu g/m^3$. Ozone was dispensed during autumn 1983 and from April to October 1984, excluding rainy days, at a concentration of 80-120 $\mu g/m^3$ for 7 hours per day, as well as in 1985/86, depending on the time of year between 30 and 180 $\mu g/m^3$ for 12 hours per day, and since week 45/1986 for 21 hours per day (Figure 2).

Table 1.--Concentrations (mg l^{-1}) of major cations and anions in simulated rain.

SO_4^{2-}	NO_3^-	Cl^-	PO_4^{3-}	Pb^{2+}	
5.1	2.8	1.5	0.1	0.05	
NH_4^+	Mg^{2+}	Ca^{2+}	K^+	Na^+	Cd^{2+}
0.3	0.3	0.8	0.5	0.8	0.005

The two rain treatments (pH 4.0 and pH 5.0) are both dispensed with a separate pump, with the storage tank holding the stock solution at a dilution ratio of 1:10 for pH 4.0, and 1:100 for pH 5.0. The exposure is regulated by flow rate valves, at a ratio of approximately 1:100. The chemical composition of the artificial rain for the pH 4.0 treatment is shown in Table 1. The pH 5.0 treatment receives the same ions at a dilution of approximately 1:10.

Artificial rain or fog is applied weekly (15 l/m^2) through different nozzle types (Table 2), which have been installed in the chamber inlet. To simulate different wet deposition properties, precipitation was applied as rain until summer 1986, in summer 1986 as drizzle rain, and in winter 1986/87 as fog (Table 2).

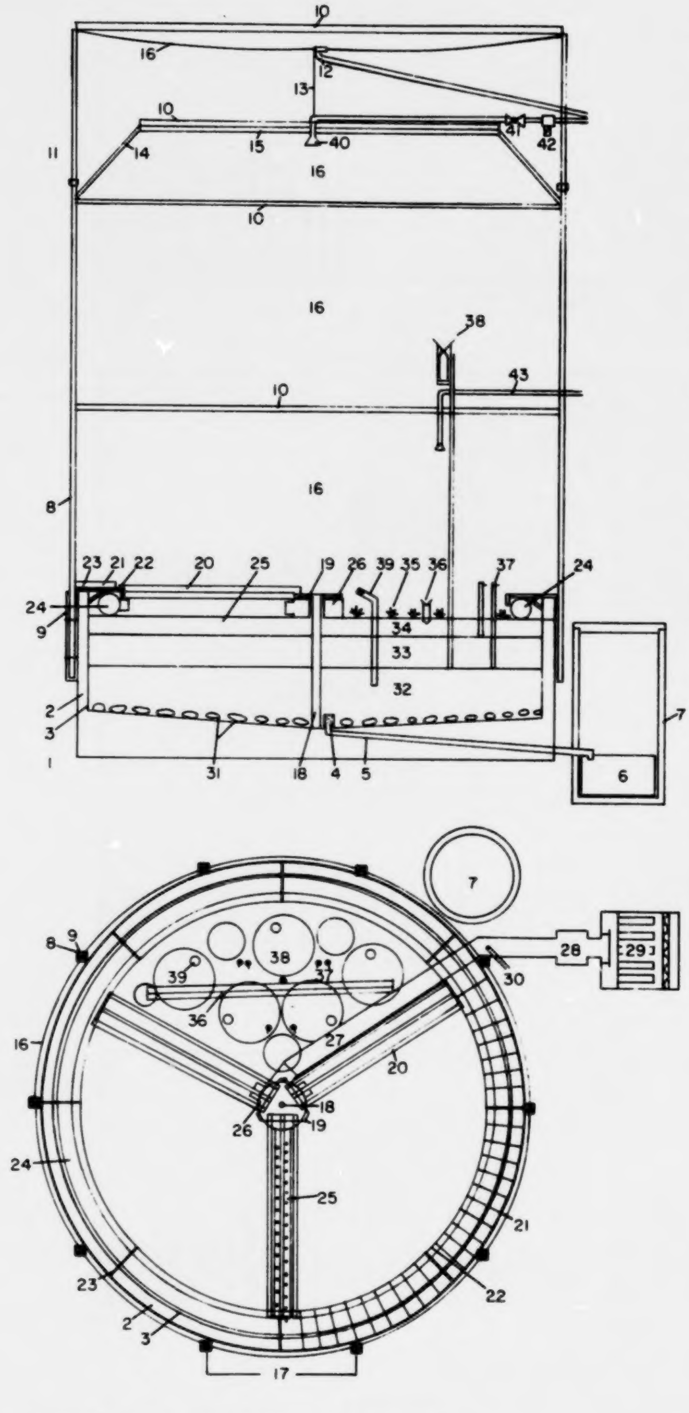
In addition, potassium bicarbonate impregnated filters (surface active monitoring) were installed in each chamber, to determine the weekly deposition rate of acidifying gases and non-sedimenting aerosols, as sulphate, nitrate and chloride ion concentrations in the dissolved filter material (Dammgen et al. 1985).

Plant Material and Soil

The following tree species were chosen for the experiments: Norway spruce *(Picea abies* (L.) Karst.; cloned material from FVA Freiburg), silver fir *(Abies alba* Mill.; originating from Alpirsbach, Black Forest) and European beech *(Fagus sylvatica* L.; originating from Münsingen, Swabian Albs). During the winter 1982/83 the young trees were kept in a greenhouse and planted into the soil lysimeters in March 1983, resulting in groups of five older (eight years, height 80-120 cm) and three younger (five years, height 30 cm) trees of each species.

Table 2.--Different types of nozzles installed in the open-top chambers

Nozzle type	Droplet size	Intensity	Precipitation form
Pneumatic atomization nozzle full cone, internal mixing, 60°	70 μm	0.5 mm/h	fog
Tangential full cone 90°	400 μm	2.5 mm/h	drizzle-rain
Axial-flow full cone, 120°	600 μm	20 mm/h	general-rain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1. basement of concrete
2. lysimeter-walls, concrete 80 x 8 cm, Ø 3m
3. sealing up of concrete with PE-foil 2mm
4. drain for percolating water
5. PE-tube 3/4"
6. PE-container 60 l
7. drainage-shaft, h=110 cm, d=60 cm
8. frame of coated iron-tubes 1/2"
9. mounting for the frame
10. coated strip iron 30 x 3 mm
11. holding device for rain-shelter
12. rain outlet
13. line to strain the rain-shelter foil
14. frustrum 45°, 50 cm
15. Al-profile for stabilization
16. PVC-foil 0,2 mm, UV-stabilized
17. foil-door
18., 19. central support for footbridge
20., 21. footbridge
22., 23. peripheral support for footbridge
24. annular ventilation tube, d=125 mm
25. ventilation tube between center and annulus
26. central air-distribution
27. air-duct from blower
28. blower 2200 W, 56m^3/min
29. filter element with carbon-cartridges and particle-filter
30. dispensing teflon-line for gases
31. draining stone-material
32.-34. soil horizons
35. ground-flora
36. sampling-duct for crown leachate
37. ceramic candles for soil solution
38. bulk sampler
39. rhizoscope tube
40. rain nozzle
41., 42. magnetic valve, pressure control valve, water clock
43. sample-line to analysers

Figure 1.--Schematic of open-top chamber with soil lysimeter.

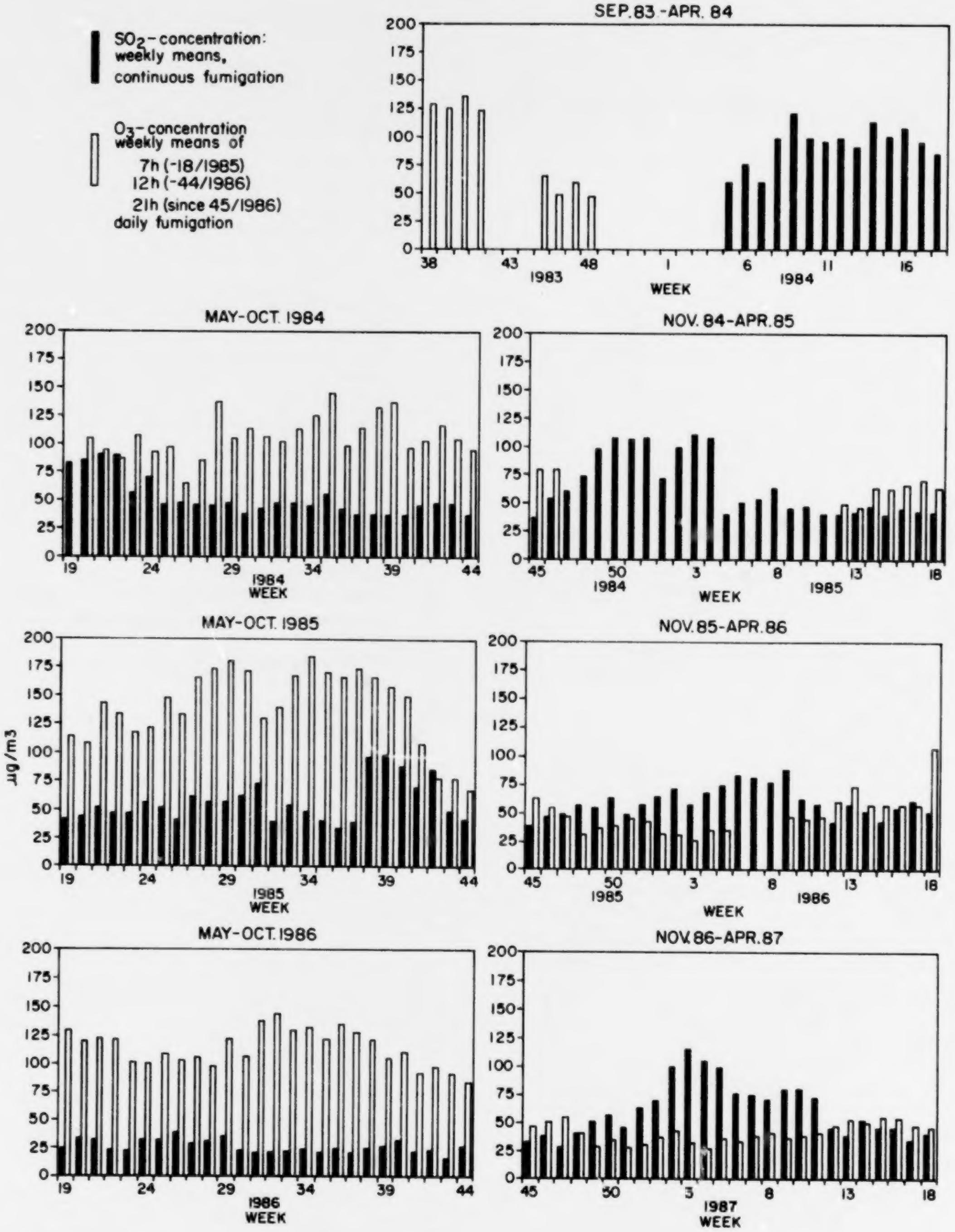

Figure 2.--Annual pattern of O_3 and SO_2 concentrations ($\mu g\ m^{-3}$) from September 1983-April 1987 in the open-top chambers for the O_3, SO_2 and $SO_2 + O_3$ treatments.

Although the trees were planted in degradable containers, with no damage to the roots, they still showed obvious signs of reduced shoot length in 1983. The soil in the lysimeter (acid brown-earth) originated from an older stand of beech-fir-spruce on a medium red sandstone derived soil in the northern Black Forest and was pre-burdened with high acid rates. (1100 mol H^+ ha^{-1} a^{-1}, mean pH 3.65, 97 kg SO_4^{2-}, 60 kg NO_3^- $ha^{-1}a^{-1}$). Ground vegetation, top litter layer, top humus layer and the mineral soil were separated and transferred into the lysimeters. Some of the stones from the mineral soil were placed on the lysimeter floor as a drainage layer (Fig. 1).

Analytical Methods

Samples of rain solutions, crown leachate, and water percolating through the soil are collected weekly, weighted and filtered immediately after sampling. The ion concentrations (Ca, Mg, K, Mn, Zn, Al, SO_4) are analyzed with usual methods (ion chromatography, atomic absorption, spectroscopy).

Analysis of tissue elemental concentrations (Ca, Mg, K, Mn, organic and inorganic S), determinations of chlorophyll and proline, and extraction and determination of peroxidase and glutamate dehydrogenase were carried out on freeze-dried plant material as described by Bender et al. (1986). Extraction of the free amino acids and carbohydrates (glucose, fructose, sucrose) was carried out according to Grunhage and Jager (1982). For analysis of free amino acids an automated amino acid analyzer (Biotronik LC 6000) was used and sugars were determined enzymatically. Simultaneous measurements of photosynthesis and transpiration were made by a recently developed CO_2/H_2O porometer (minicuvette system), which allows quick and reproducible determinations of photosynthetic capacity of conifer branches. A description of the system is given in detail by Lange et al. (1985).

A twig section was enclosed in a climatized chamber with attached light source. Transpiration and CO_2 gas exchange was measured by an infrared differential gas analyzer under defined light conditions. All measurements were carried out at standard conditions, at an air temperature of 20° C in the cuvette, and a relative humidity of approximately 55% (equivalent to a dewpoint of 10° C in the incoming air) of the abient air around the shoots.

Results and Discussion

Mineral Cycling

The investigaitons on mineral cycling in the model ecosystems follow the concepts and methods of the compartment model developed in the course of the German Solling-MAB-project (Ulrich et al. 1979; Ellenberg et al. 1986). Among other things, this model represents the changes rain undergoes, in passing through the tree canopy and the ground.

Data from the 1986 growing season serve as an example (Figure 3). If one considers the relative changes in the elemental fluxes in each fumigation treatment as percent of the controls (CF), it can be shown with spruce that SO_2 increases sulfate, manganese and H^+ in throughfall water as well as in seepage water. The acidification of the whole system is accompanied by leaching of calcium, magnesium and zinc from the needles, and calcium, magnesium and aluminum from the soil. The needle content of sulphur and manganese in spruce is increased, whereas calcium and magnesium concentrations remained nearly unchanged in October 1986 compared to the controls. In contrast, these values were distinctly reduced in the SO_2 treatments (SO_2 and $SO_2 + O_3$) in autumn 1984, especially in the case of magnesium (Arndt et al. 1985).

In the first years of exposure (1984/85) the effects caused by SO_2 were further increased in the case of simultaneous fumigation with SO_2 and O_3 (Arndt et al. 1985; Seufert and Arndt 1986). In 1986 the difference between the SO_2 and the $SO_2 + O_3$ treatment is not as obvious as in the years before. The trends are the same, but the SO_2 -effects seem to be raised. The additional analysis of Zn in 1986 shows a clear enrichment in throughfall in all fumigation treatments. Zn is the first element with a clear response to the fumigation with ozone alone.

The leachability of elements as affected by SO_2 and/or O_3 is shown as canopy differences in summer and winter seasons 1985-87 (Figure 4). Again, it is obvious that the combined exposure caused the highest ion leaching, while O_3 only increased zinc content in throughfall, especially in summer, when O_3 was given in higher concentrations than in winter (Figure 2). Further the effects of the different forms of simulated precipitation used between 1985/87 on elemental leaching become especially evident, when comparing summer and winter data of the 2 years. Compared to the year before with rain, leaching effects as a result of pollutant fumigation were higher under drizzle conditions (summer 1986), and were most pronounced in winter 1986/87 when fog was applied. It seems reasonable to conclude that some effects of long term application of air pollutants on mineral cycling in the model ecosystems can be observed in a similar way in diseased European forests. Most noticeable is the increased canopy leaching of easily mobilized elements and soil acidification. Zottl and Mies (1983), for example, observed zink deficiency in spruce trees showing symptoms of decline in the Black Forest. Bosch et al. (1983) and Zech et al. (1985) attribute calcium and magnesium deficiency of spruce needles at higher elevation in the Bavarian Forest to increase foliar leaching caused by acid deposition. It has also been shown by Ulrich et al. (1979) and Ulrich (1985) that soil acidification due to air pollution causes mobilization and accumulation of cation acids (Al, Mn). In this respect the ratio of Al or heavy metals to concentrations of nutrient elements in soil (e.g. Ca:Al ration) is important for including toxic reactions in trees (Matzner et al. 1985). Although an increase of A1 in soil solution as a result of SO_2 fumigation was found in the present investigation, there is little evidence for toxic effects, because our soils are not too poor in calcium.

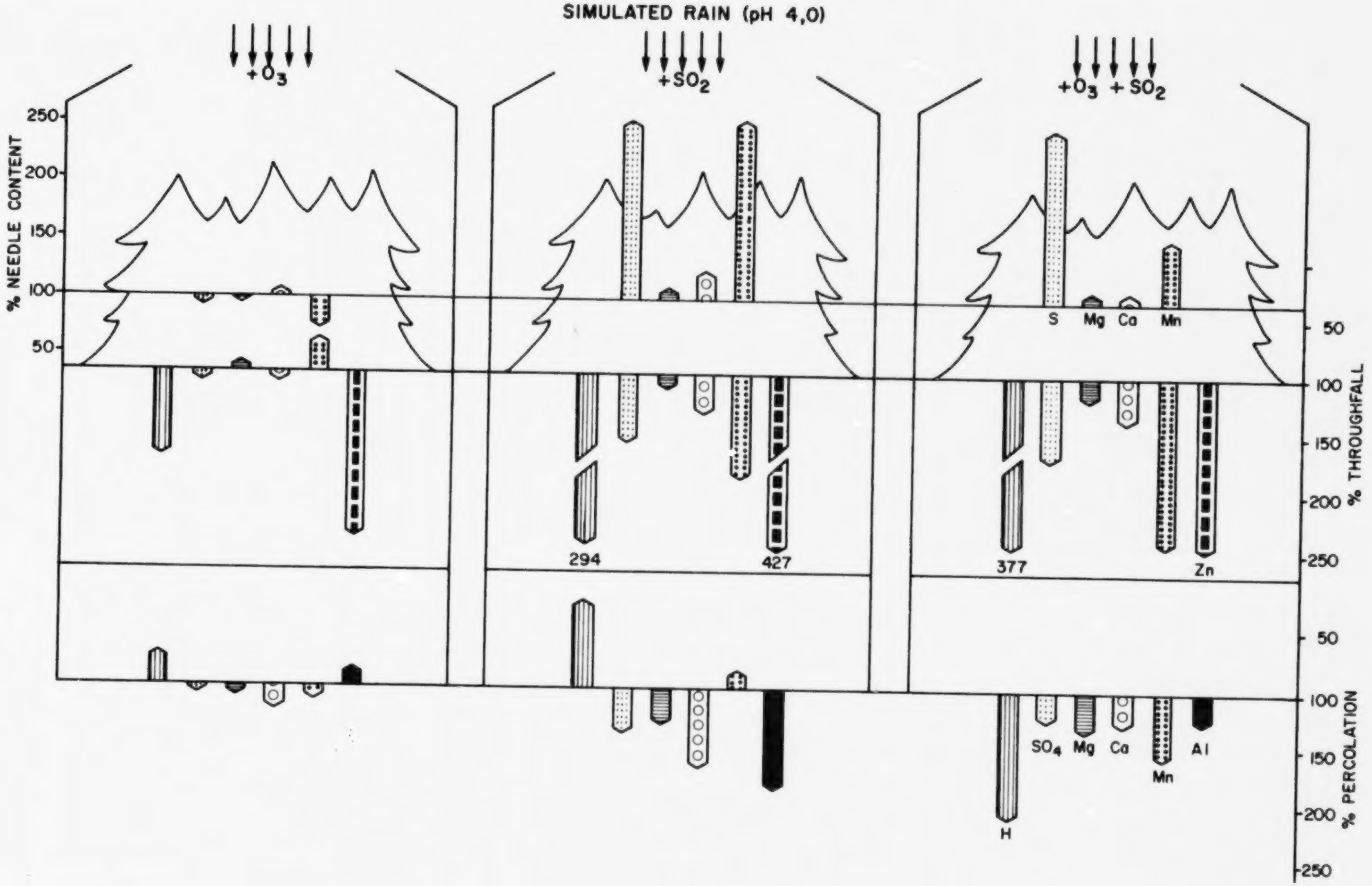

Figure 3.--Differences in the mineral cycling of the pollutant-fumigated model ecosystems as % of control in 1986. Changes in throughfall and percolation based on calculations of elemental flow rate (mean of 33 weekly samples), which is the product of concentration and total water volume. Differences in foliar nutrient concentrations are from spruce (Sampling date: October 1986).

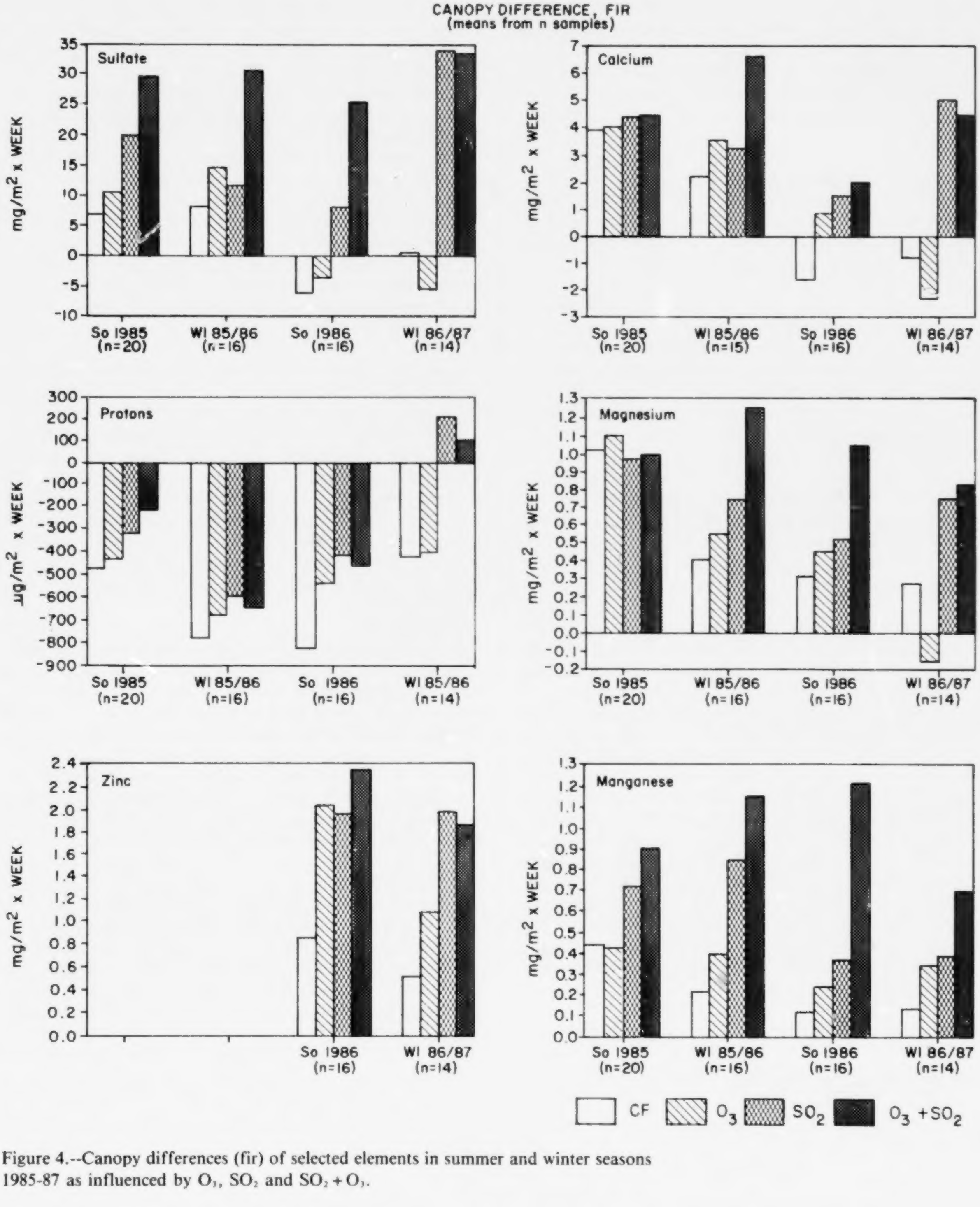

Figure 4.--Canopy differences (fir) of selected elements in summer and winter seasons 1985-87 as influenced by O_3, SO_2 and $SO_2 + O_3$.

The fact that manganese increased in all compartments of the SO_2 treatments (SO_2 and $SO_2 + O_3$) is in accordance with results found in some German forests (Gärtner 1985). This is also true in the West-Whitecourt study in Canada, where Legge (1980) found increased foliar manganese concentrations because of an increased rate of soil acidification caused by high sulphur gas immissions.

Physiological and Biochemical Effects

The objective of this aspect of our study was to determine whether tree physiological responses and metabolite levels are altered by near ambient concentrations of SO_2, O_3 and acid precipitation and whether these responses are modified by pollutant mixtures.

A comparison of mean rates of net photosynthesis and transpiration at different light intensities of pollutant fumigated and non fumigated spruce and fir trees is made (Figure 5). Current foliage of spruce in 1986 showed reduced net photosynthesis in the SO_2 treatment, while CO_2-uptake of trees exposed to O_3 or $SO_2 + O_3$ was not affected compared to the controls. Similar to the photosynthetic responses, transpiration rates were lowest in trees exposed to SO_2 alone, and highest in needles of plants in clear air. Light-response curves for fir indicate significant reductions in net photosynthesis and transpiration for those trees exposed to $SO_2 + O_3$. In contrast, there were only slight differences in photosynthesis between the other treatment groups. The transpiration rate did not follow the photosynthetic response pattern in all cases.

Alteration in metabolic plant processes during the exposure to the gaseous pollutants have been monitored by analysis of several biochemical parameters. Figure 6 shows the effects of SO_2 and O_3 (alone and in combination) on enzyme activities and selected metabolites in current year's needles (1986) of spruce and fir. Results of the first year's (1984/85) have been published (Bender et al. 1986). Due to the SO_2 fumigation (SO_2 and $SO_2 + O_3$) the foliage sulphur content in both species increased. These increases in total foliar sulphur are mainly attributed to an accumulation of inorganic sulphur (sulphate sulphur), whereas organic sulphur increased only slightly. Besides that, pollutant fumigation stimulated the activities of peroxidase and glutamate dehydrogenase, and diminished the concentrations of glucose and fructose and, partly, of sucrose. Proline levels, which increase substantially in response to water stress, only increased in fir, especially in the O_3 and $SO_2 + O_3$ treatment. No significant effects on chlorophyll content were measured in the current year needles in October 1986.

Moreover, changes in the concentration of free amino acids indicated the altered cellular function under long-term pollution stress. The concentrations of free amino acids in two needle age classes of spruce are shown in Table 3. The total amount of all amino acids investigated increased significantly in the O_3 treatment (+33%/+30%) and in the $SO_2 + O_3$ treatment (+57%/+55%) in either needle age class compared to the controls. These increases were mainly caused by an increase in the concentrations of the amides glutamine and asparagine. Significantly higher concentrations were also found for serine, glycine, and proline, especially in needles exposed to the pollutant mixture. SO_2 alone increased the concentrations of glutamic acid and glutamine significantly in needle age class 1985. The higher concentrations of arginine in both needle age classes of O_3 and $SO_2 + O_3$ fumigated trees are noteworthy. Arginine is a precursor of polyamines and there is much evidence that changes in the concentration of polyamines (e.g., putrescine) are also highly indicative of pollutant related stress situations in plants (Priebe et al. 1978; Jäger 1982).

Overall, one can state that the long-term exposure of young trees to gaseous air pollutants has affected physiological and biochemical processes in a variety of ways. While the single effects of SO_2 in comparison to O_3 were definitely dominant in the first years of the study (Bender et al. 1986), the present results show that effects of the added gases now occurred in all treatment groups. However, the combination of SO_2 and O_3 often resulted in responses that were greater than the single effects. Nevertheless, comparisons of needles at different developmental stages have shown that some effects become obvious only with increasing needle age (Bender et al. 1986).

Conclusions

The results of the present study have clearly shown that long-term effects of near ambient levels of air pollutants can be identified either directly in above-ground plant parts or in the soil of the model ecosystems with young forest trees. These changes in different compartments of the system suggest that there may be close interactions between effects in the canopy and in the soil. Moreover, the results demonstrate that mineral cycling, tree physiology or metabolic processes were often more affected by pollutant mixture than by single pollutant exposure. It is also remarkable that similar pollutant effects found in the present investigation can be observed in diseased European forests. Principally model ecosystems represent only an approximated description of reality, and transferability of results to actual field situations is, of course, limited. The main limitations of our approach are due to the use of young trees, and due to the disturbance of the soil during the construction of the experimental system. However, these experiments in model ecosystems are only one step in an experimental chain, which also includes measurements in older stands as well as in open-top chambers placed around 15 year old spruce in a stressed forest near Stuttgart.

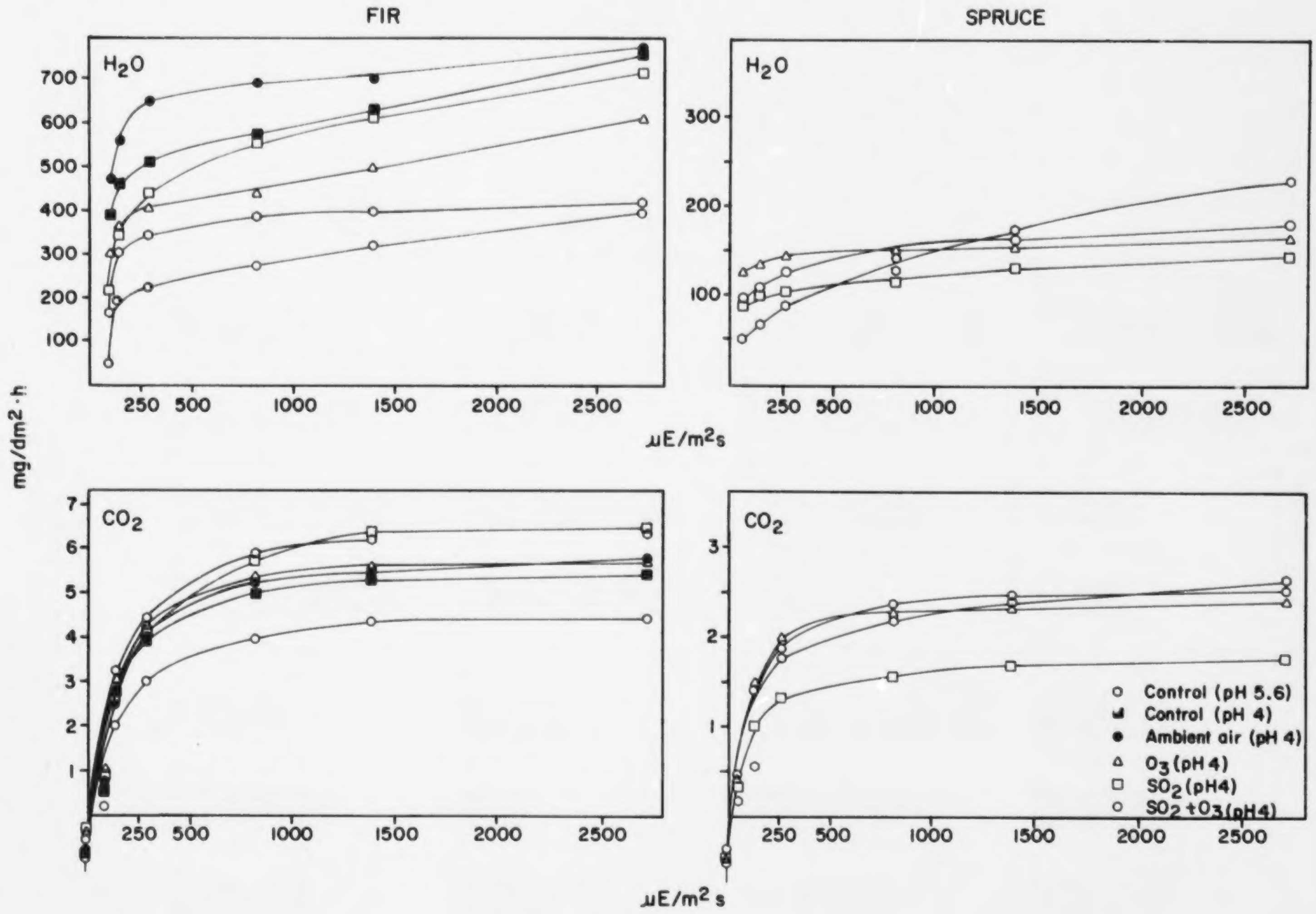

Figure 5.--Effect of SO_2 and O_3 (alone and in combination), and simulated acidic rain on mean net photosynthesis (mg CO_2 $dm^{-2}h^{-1}$; lower part) and transpiration (mg H_2O $dm^{-2}h^{-1}$; upper part) of spruce and fir at different light intensities.

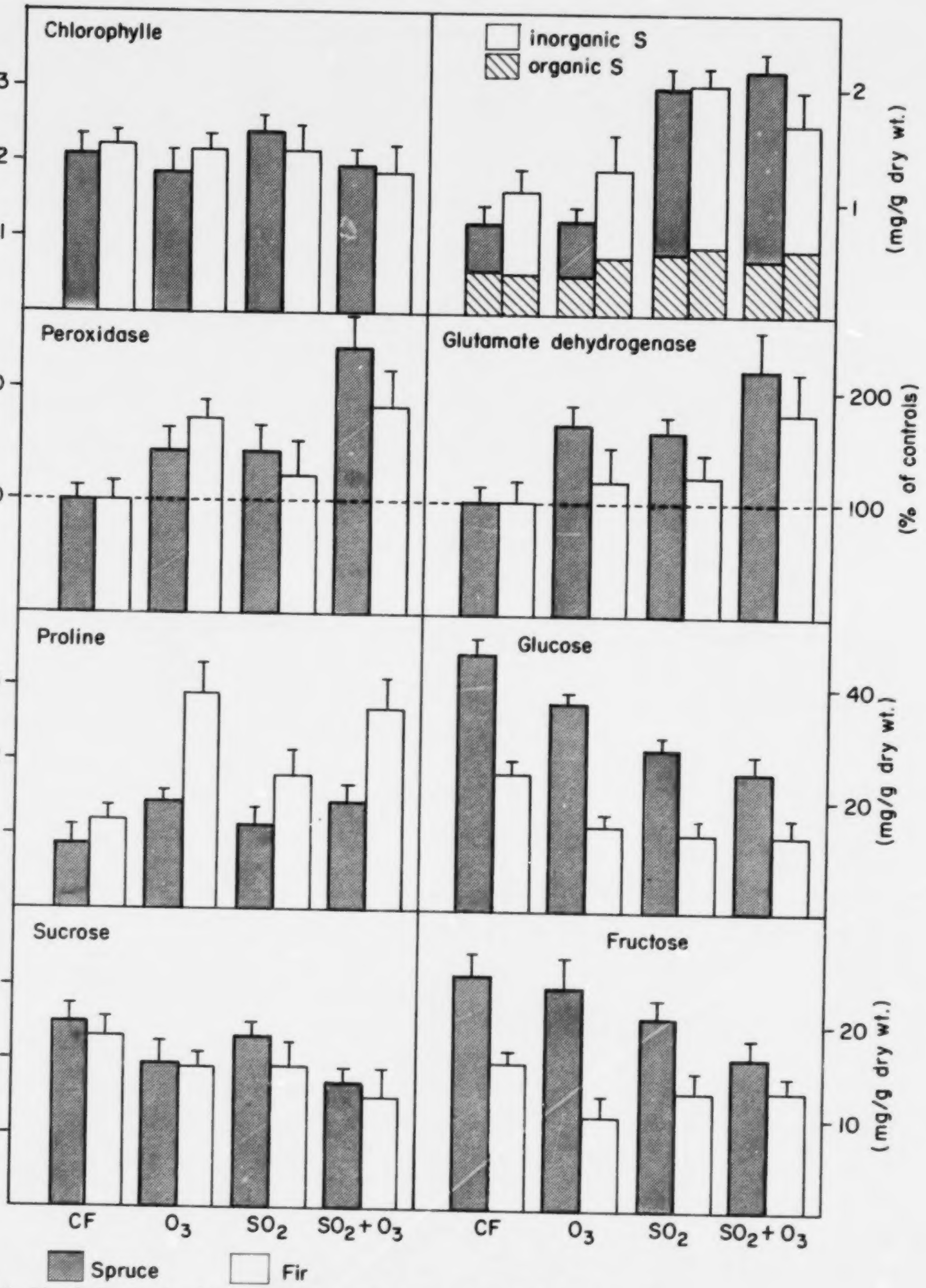

Figure 6.--Metabolite levels of spruce and fir needles exposed to SO_2 and/or O_3. Bars represent means of four subsamples per treatment ± S.D. Enzyme activities (peroxidase, glutamate dehydrogenase) are given as % of controls (CF). Proline concentrations were determined according to the method of Bates et al. (1973).

Table 3.--Mean concentrations of free amino acids (μmoles/g dry matter) in spruce needles as influenced by O_3, SO_2, and $O_3 + SO_2$; Values represent the average of 4 samples per treatment, (sampling date: 20.10.85)

Treatment	Control		O_3		SO_2		$O_3 + SO_2$	
	1984	1985	1984	1985	1984	1985	1984	1985
Asp	2.93	2.18	3.08	2.45	2.12	1.78	3.85	2.68
Asn	3.68	4.96	3.76	6.02*	3.84	5.18	5.70*	11.45*
Thr	0.19	0.61	0.38	0.77	0.24	0.47	0.22	0.81
Ser	2.45	1.47	2.45	2.82*	3.22	1.62	4.52*	2.60*
Glu	4.81	2.38	6.80	2.45	4.91	3.21*	5.24	2.28
Gln	8.34	10.90	14.69*	14.80*	10.90	13.40*	15.00*	16.20*
Pro	0.36	0.31	0.45	0.45	0.43	0.49	1.02*	0.84*
Gly	0.32	0.19	0.43	0.36*	0.31	0.16	0.43	0.28
Ala	1.17	0.82	1.35	0.71	0.94	0.62	1.62	0.60
Val	0.38	0.58	0.36	0.62	0.40	0.42	0.58	0.56
Ile	0.09	0.22	0.08	0.30	0.08	0.09	0.09	0.09
Leu	0.16	0.24	0.18	0.20	0.18	0.20	0.09	0.26
Tyr	0.28	0.16	0.36	0.18	0.30	0.22	0.58	0.09
Phe	0.16	0.28	0.24	0.30	0.22	0.18	0.18	0.18
Lys	0.18	0.32	0.22	0.29	0.16	0.16	0.20	0.36
His	--	0.28	--	0.26	0.18	0.40	0.28	0.22
Arg	1.62	1.42	2.82*	2.55*	2.02	1.54	3.14*	2.96*
Sum	27.12	27.32	37.56*	35.53*	30.45	30.14	42.74*	42.46*
(% Control)	(100)	(100)	(138)	(130)	(112)	(110)	(157)	(155)

Significantly different from the controls ($P < 0.01$) according to Duncan's multiple range test.

[a] Below the limit of detection.

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Nutrient Status of Some Contrasting High-Elevation Forests in the Eastern and Western United States

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Abstract

Comparisons were made of the chemical compositions of soil, soil solution, and foliage in spruce-fir forests in the Great Smoky Mountains National Park in North Carolina, Whiteface Mountain in New York, and on the western slope of the Cascade Mountains in Washington. Soils from all sites had similiar and very low base saturations (often less than 10% by the sum-of-cations method). Soil solution chemical compositions varied considerably, however, with the Smokies sites having the highest NO_3, SO_4^{2-}, Al^{3+}, *total anion, and total cation concentrations, followed by the Whiteface and Cascade sites, respectively. The relationships between these patterns and theoretical considerations of soil-soil solution equilibria are discussed, as is the potential for Al toxicity to red spruce in the two eastern sites.*

Introduction

Numerous hypotheses have been proposed to explain the decline and dieback of spruce-fir forests in the northeastern United States and in the Federal Republic of Germany (see reviews by Johnson 1983 and McLaughlin 1985). Several of these hypotheses point to air pollution as the cause: (1) ozone and/or acid fog damage to foliage and subsequent excessive foliar leaching, leading to Mg or Ca deficiency (Prinz 1985); (2) soil and/or soil solution acidification, leading to Al^{3+} toxicity to roots and/or Mg, K, or Ca deficiencies (Ulrich 1983, 1987; Ulrich et al. 1980); and (3) excessive N deposition, leading to increased NO_3^- leaching (with all the attendant effects listed above) and reduced frost hardiness (Friedland et al. 1984; Evans 1986). Other non-pollution-related hypotheses invoke climatic fluctuations or natural stand dynamics (Hornbeck et al. 1987) as probable causes. In the context of the latter, it is important to note that inexplicable forest declines and diebacks have occurred in many unpolluted parts of the world (Mueller-Drumbois 1983). The coincidence of air pollution and forest decline calls for investigation of potential cause-and-effect relationships, but it certainly does not establish them that such relationships exist.

As part of the Integrated Forest Study on Effects of Atmospheric Deposition, we are characterizing the nutrient cycles of spruce-fir ecosystems on Whiteface Mountain in New York, the Great Smoky Mountains in North Carolina near the Tennessee-North Carolina border, and the Cascade Mountains in Washington. Detailed analyses of nutrient cycling in these forest ecosystems, which represent a range of conditions in climate, air quality, and forest health, should test some of the hypotheses that have been posed. These studies are currently in progress, and a full report of our nutrient cycling analyses will be presented when the work is completed. In this paper, we present some preliminary data on vegetation, soil, and solution chemical compositions.

Sites

Great Smoky Mountains

We are characterizing nutrient cycles at two sites in the Great Smoky Mountains. These two sites, named Becking and Tower, are located at elevations of 1800 and 1740 m, respectively, near Clingmans Dome in the Great Smoky Mountains National Park. The Becking Site was so named because it is located on one of the vegetation inventory plots established by Rudolph Becking in 1976 (Becking and Olson 1978). The Tower site was so named because a meteorological tower for detailed atmospheric deposition measurements is located there. The climate is characterized by cool summers and cold but not severe winters. Stephens (1969) reported average temperatures of -1.8° C for February and 14°C for July for the 1524-m elevation in the park and an average annual precipitation of 228 cm/year at that elevation. Precipitation is fairly evenly distributed. Snow cover varies considerably from year to year. A snowpack seldom lasts through the winter, although snowfall typically occurs approximately 50 days per year. Soils at both sites are Umbric Dystochrepts derived from Thunderhead Sandstone. Boulders are common in both soils, especially in the lower horizons, and especially at the Becking site, where many surface outcrops are common. The overstory vegetation at both sites consists primarily of old-growth (approximately 200-300 year old) red spruce *(Picea* *rubens*) with occasional Frasier fir (*Abies fraseri*), most of the latter being in a state of severe decline due to attacks by the balsam woolly adelgid. The sites differ in two respects: the red spruce at the Tower site appear to be more vigorous than those at the Becking site, and the Becking site has a greater Fraser fir component, in both the overstory and the understory, than the Tower site. The understory at the Becking site is dominated by patches of Frasier fir regeneration ranging from 4-12 cm in diameter and undergoing significant mortality, presumably from the balsam woolly adelgid. Other understory species of note are blackberry (*Rubus canadensis*), vaccinium (*Vaccinium erythrocarpum*), witch hobble (*Virburnum alnifolium*), American mountain-ash (*Sorbus americana*), oxalis (*Oxalis acetosella*), various ferns, and abundant mosses. The understory at the Tower site consists of patches of Fraser fir with occasional red spruce regeneration, blackberry, witch hobble, vaccinium, American mountain-ash, and various ferns.

Whiteface Mountain

Whiteface Mountain (summit elevation 1483 m) is located near Wilmington, New York, in the northeast section of the Adirondack Mountains (44°N, 73°W). The study area is a narrow west-northwest-trending drainage basin (elevation 970-1100 m) on the flank of Esther Mountain, the eastern peak of the Whiteface massif. Mean annual temperatures range between 4.8°C at the base meteorological station (600 m) and 0°C at the Whiteface summit station. The growing season is approximately 90 days (Holway and Scott 1969). Annual precipitation averages 100 cm at the base and increases substantially with elevation. Approximately 30% of the precipitation occurs as snow. A seasonal snow cover normally persists at the study site from November through April, with peak accumulation of about 150 cm (30 cm water equivalent) occurring in February or March. Frost extending to the depth of the forest floor has been observed in the first 2 years of the study and may be common. Continuing observations suggest that the summit of Whiteface can be immersed in clouds up to 30% of the year and the study area may be cloud covered 10% of the year (Ted Arons, Atmospheric Sciences Research Center, personal communication, 1987), making cloud water a potentially significant addition to precipitation. Soils are primarily Cryohumods and Borofolists derived from Precambrian anorthosite, with an average depth to bedrock of 40 cm. Areas of well-developed Spodosols up to 1 m deep and organic mats with little or no mineral soil development overlying anorthosite boulders are also common, especially at the higher-elevation plots. Balsam fir [*Abies balsamea* (L.) Mill.], red spruce (*Picea rubens* Sarg.), and white birch [*Betula papyrifera* var. *cordifolia* (Reg.) Fernald] dominate the study area. American mountain-ash (*Sorbus americana* Marsh.) is also present. The species composition represents a typical forest at 100-m elevation in the Adirondacks; the study area has not been distrubed by fire or logging in recent history (Ketchledge, personal communication, 1987) and can be considered, in general, mature and overmature forest.

Cascade Mountains--Findley Lake

The Findley Lake study site lies within the Cedar River watershed, approximately 65 km southeast of Seattle, Washington. It is located on the western slope of the Cascade Mountains at an elevation of 1130 m. Mean annual temperature is 5.4°C. Mean annual precipitation is 273 cm, with a snowpack from 2 to 7 m. The soil is a Spodosol, which has tentatively been classified as a Typic Cryohumod by the Soil Conservation Service National Cooperative Soil Survey (Dahlgren 1984). The parent material primarily consists of andesite moraines 1 to 3 m thick on top of fractured andesite. Mount St. Helens W and Y ash deposits from 4 to 25 cm thick overlie these materials (Meier 1981). The area is part of the *Abies amabilis* vegetation zone (Franklin and Dyrness 1973). The stand is dominated by approximately 180-year-old Pacific silver fir trees (*Abies amabilis*), in association with mountain hemlock (*Tsuga mertensiana*) and western hemlock (*T. heterophylla*). Major shrubs include vaccinium (*Vaccinium membranaceum* and *V. ovafolium*), Sitka mountain-ash (*Sorbus sitchensis*), and alder (*Alnus sinuata*).

Methods

At each site, soils, litter, and vegetation were sampled and are currently being analyzed for nutrient content. At present, we are able to report foliar N, P, K, Ca, and Mg and soil total N and exchangeable Al^{3+}, Ca^{2+}, Mg^{2+}, $K^{+}$and Na^{+}. Vegetation biomass was determined from regression equations based on diameter at breast height. In addition to bulk precipitation and throughfall collections at each site, intensive measurements of atmospheric deposition and canopy interactions are being made at the Great Smoky Mountains Tower and Whiteface Mountain sites. The intensive deposition measurements include atmospheric concentrations of cloud water, particles, SO_2, HNO_3, and O_3, coarse particle dry deposition rates, rain and throughfall event chemistry, and standard meteorological parameters measured from above-canopy towers (Lindberg et al., in press). Tension lysimeters (10-kPa constant tension) constructed from fritted glass buchner funnels (2- to 4- μm pore size) were installed within major horizons at each site. Samples were either collected monthly or bulked into monthly samples for analyses if collected more frequently.

All chemical analyses on samples from the Smokies and Whiteface sites were performed by the Analytical Chemistry Division at Oak Ridge National Laboratory (ORNL), and all chemical analyses on samples from the Findley Lake site were performed at the College of Forest Resources at the University of Washington. Samples are being exchanged between the two laboratories for cross-checks on analytical precision, and corrective action is being taken the result of the second analysis is not comparable to the first. (For instance, all solution SO_4^{2-} data from the Findley Lake site reported here come from ion chromatograph analyses because of problems uncovered with colorimetric analyses of SO_4^{2-} as a result of these comparisons.) At ORNL, foliar and soil analyses for total N were performed by Kjeldahl digestion. Analyses for foliar P, K, Ca, and Mg were done by perchloric acid digestion followed by Techincon Autoanalyzer analysis. Soil exchangeable cations were determined by extraction with 1 **M** KCl followed by atomic absorption analyses for Al, Ca, Mg, K, and Na. Total C in soils was done by LECO combustion. Solutions were analyzed for pH, conductance, and alkalinity (by titration to pH 5); major anions were analyzed by Dionex ion chromatograph; Ca, Mg, K, and Na were analyzed by atomic absoprtion, Al by graphite furnace, and total N by Kjeldahl digestion (Technicon block digestion followed by Technicon Autoanalyzer analyses for NH_4^+).

Results and Discussion

At this time, we have sufficient data to report only on volume-weighted average bulk precipitation, throughfall, and soil solution concentrations of anions and cations, and concentrations of some elements in foliage and soil. More detailed information on atmospheric chemistry at one of the Smokies sites is given by Lindberg et al. (in press). In later papers, we will report on atmospheric deposition, internal fluxes, and ecosystem contents in full detail.

Soils from the four sites are relatively similiar with respect to their base saturation profiles: fairly high in organic and surface mineral horizons but quite low in subsurface horizons (Table 1). The Smokies soils tend to have somewhat lower base saturations than either the Whiteface or Findley Lake soils, but the differences are not great. Total soil N and C:N ratios differ greatly between the Findley Lake and Smokies sites (no data is yet available for the Whiteface site), indicating that the Findley Lake soils have less than available N and less total N than the Smokies soils.

Table 1. Exchangeable cations, cation exchange capacity (CEC), and percent base saturation (BS) in soils from the study sites

Horizon	Depth	CEC[a]	Al	Ca	Mg	K	Na	BS	N	C	C:N
	cm	*meq/100 g*						*Percent*			
Great Smoky Mountains -- Becking site											
Oie		8.10	4.66	2.08	0.71	0.56	0.07	42	0.80		
Oa		19.90	14.88	2.79	1.41	0.63	0.15	25	1.58		
A	0-20	15.40	14.43	0.29	0.40	0.20	0.07	6	0.94	13.58	14.50
Bwl	20-33	7.50	7.10	0.10	0.14	0.13	0.03	5	0.26	3.62	14
Bw2	33-64	1.70	1.59	0.02	0.02	0.07	0	6	0.03	0.48	16
Great Smoky Mountains--Tower site											
Oie		18.70	6.21	8.45	2.04	1.92	0.10	67	1.74		
Oa		17.50	13.99	2.04	0.82	0.59	0.08	20	1.54		
Al1	0-3	10.10	9.54	0.21	0.20	0.14	0.02	6	0.32	6.39	19.90
Al2	3-21	8.70	8.21	0.12	0.16	0.13	0.04	5	0.39	5.70	14.80
Bw1	21-36	5.20	4.87	0.07	0.10	0.10	0.03	6	0.28	3.43	12.30
Bw2	36-61	2.60	2.43	0.03	0.05	0.06	0.05	7	0.12	1.35	11.20
Whiteface Mountain											
Oa		18.10	4.50	10.40	1.60	1.30	0.30	75			
Bhs		9.20	8.50	0.40	0.10	0.10	0.10	8			
Bs		3.61	3.20	0.20	0.01	0.10	0.10	11			
Cascade Mountains -- Findley Lake site											
A		1.27	0.85	0.23	0.08	0.11	0	33	0.08	1.74	21.80
E		26.95	25.50	0.66	0.26	0.40	0.13	5	0.25	7.14	28.60
Bs		10.50	9.95	0.24	0.08	0.14	0.09	5	0.23	9.93	43.20
BC		0.99	0.83	0.09	0.03	0.05	0	16	0.11	3.55	32.50

[a] Calculated by sum-of-cations method.

Table 2. Volume-weighted average concentrations of major cations and anions in solutions at the study sites all values are in molc/L except for A1, which is in mol/L)

Sampling level	H^+	Al^{3+}	Ca^{2+}	Mg^{2+}	K^+	Na^+	NH_4^+	Cations[a]	HCO_3^-	SO_4^{2-}	NO_3^-	CL^-	$H_2PO_4^-$	Anions
Great Smoky Mountains--Becking site														
Precipitation	90.10	2.60	30	7	7	7	9	154	0	67	16	13	0.21	95
Throughfall	239	4.90	60	15	17	17	10	239	0	120	30	19	0.18	169
A	163	56	61	34	25	18	1.20	471	0	163	183	46	0.13	391
Bw1	113	64	70	32	12	15	0.60	437	0	126	194	22	0.06	381
Bw2	69	66	60	30	13	15	0.60	386	0	124	201	20	0.06	345
Great Smoky Mountains--Tower site														
Precipitation	112	1.03	36	8	10	9	6	189	0	85	21	12	0.26	118
Throughfall	103	1.90	52	15	27	15	22	239	0	126	42	22	0.83	198
A	203	80	50	46	35	46	1.60	619	0	163	284	61	0.16	510
Bw1	50	66	32	24	5	24	0.80	346	0	135	145	27	0.70	311
Bw2	44	66	41	23	7	23	1.60	346	0	126	144	27	0.08	296
Whiteface Mountain														
Precipitation	36	0.91	6	4	2	0.80	12	62	0	41	15	3	0.05	59
Thoughfall	63	1.40	33	9	11	4	10	131	0	68	12	5	0.76	86
0	82	67	69	41	3	11	1.40	274	0	187	17	11	0.06	215
Bhs	34	42	60	37	5	8	0.60	187	0	176	13	9	0.06	198
Bs	27	34	56	23	3	7	0.80	156	0	161	12	7	0.04	180
Cascade Mountains--Findley Lake site														
Precipitation	11	0.10	11	12	5	31	7	77	4	16	6	34	0.10	60
Throughfall	17	1.70	13	8	14	34	2	90	2	22	2	36	0.10	62
Oa	82	13	52	32	55	65	1.80	300	0.40	17	0.90	93	4.40	116
E	39	28	49	28	10	80	1.40	235	1.50	13	0.30	69	0.50	84
Bs	3	5	24	16	4	75	0.70	128	26	35	0.40	38	0.10	130

[a] Assuming Al is in the Al^{3+} form.

Volume-weighted average concentrations of major cations and anions in solutions at the study sites are given in Table 2. The concentrations of SO_4^{2-} in soil solutions at the Smokies and Whiteface sites are considerably higher than the concentration at the Findley Lake site, as expected, since Findley Lake is basically an unpolluted site (Johnson et al. 1977). Soil solution concentrations of NO_3^- are highest in the Smokies sites, followed by the Whiteface and Findley Lake sites. The only site with HCO_3^- in solution is Findley Lake, where it appears in the Bs horizon after the organic acids precipitate (Johnson et al. 1977; Ugolini et al. 1977). The differences in soil solution NO_3^- concentration between the Smokies and Findley Lake sites are clearly reflected in differences in soil N status, as noted above (Table 1). The patterns of soil solution NO_3^- also coincide with preliminary estimates of both N and S deposition at these sites. Based on the atmospheric N data from the initial months of the study, we estimate that inorganic N deposition rates at the Smokies sites are approximately twice those at the Whiteface site, and 3-4 times those at the Findley Lake site. Data on SO_2, particle SO_4^{2-}, and SO_4^{2-} in cloud water, rain, and throughfall collected early in 1986 suggest that S deposition will be highest at the Smokies sites, somewhat lower at the Whiteface site, and considerably lower at the Findley Lake site. Bulk deposition SO_4^{2-} concentration data (Table 2) also indicate this trend.

The dominant cation in the surface horizons of all sites is H^+, and significant amounts of Al are present in solutions from all four sites (Table 2). The Smokies sites have the highest concentrations of H^+ and Al, followed by the Whiteface and Findley Lake sites, respectively (Table 2). This is, of course, a natural consequence of the pattern in total anion concentrations at these site, coupled with the extremely acid soil conditions at all four sites. (Table 1). We have expressed Al concentrations in μmol/L instead of μmolc/L because we do not know either the exact charge distribution or the extent to which soil solution Al is in monomeric as opposed to chelated forms at this time. At the Smokies sites, some testing for monomeric Al has been conducted, and results indicate that 80-90% of soil solution Al is in inorganic, monomeric form.

Hutchinson et al. (1986) report inhibition of red spruce growth at Al concentrations of 185 μmol/L and higher in sand culture studies, and Thornton et al. (in press) report significant effects on red spruce seedling growth and on Mg, and Ca uptake with concentrations of 250 μmol/L of monomeric Al in solution culture studies. Weighted average total Al concentrations in soil solutions from both the Smokies and Whiteface sites are considerably lower than this (ranging from 56 to 80 μmol/L in the Smokies and from 34 to 66 μmol/L in the Whiteface sites), but the possibility of Al toxicity exists for a variety of reasons. First, Thornton et al. did not test concentrations lower than 250 μmol/L, and we currently have no information as to the effects of lower concentrations on red spruce. Secondly, peak concentrations of Al reached 150 and 100 μmol/L in organic and mineral horizons,

Table 3. Foliar nutrient concentrations for the study sites

Site	Species	Age class	Crown position	N	P	K	Ca	Mg
				mg/g				
Great Smoky Mountains--Becking	Red spruce	New	Upper	9.90	1.20	5.70	1.18	0.63
		New	Lower	10	1.30	6.90	1.16	0.56
		Old	Upper	9.30	0.77	3.70	2.42	0.43
		Old	Lower	11	0.78	3.80	3.11	0.46
Great Smoky Mountains--Tower	Red spruce	New	Upper	9.30	1.10	6.30	1.40	0.69
		New	Lower	10	1.10	7.80	1.30	0.57
		Old	Upper	9.50	0.77	3.90	3.95	0.58
		Old	Lower	10.40	0.76	4.40	3.70	0.53
Whiteface Mountain	Red spruce	New	Upper	10.22	0.89	3.76	2.89	0.53
Cascade Mountains--Findley Lake	Silver fir	All	Middle	11.11	1.51	6.44	5.31	0.89

respectively, in the Smokies sites, and 78 and 59 μmol/L in organic and mineral horizons, respectively, in the Whiteface sites. Thirdly, the soil solution Al concentrations reported here represent only those in gravitational soil water (i.e., the water that drains from the soil during rain events). It may well be that the concentrations of Al in nongravitational, but plant-available, soil water (e.g., soil solutions held at tensions of 10 to 1500 kPa) may be greater than those reported here.

Foliar nutrient concentrations for the four sites are given in Table 3. The low foliar N values at the Smokies sites are quite surprising, given the very high N availability in these ecosystems. Obviously, these sites are not N deficient, and the question then becomes, why do the trees take up so little N in this N-rich environment? The possibility of inhibition of N uptake by the relatively high soil solution Al concentrations comes to mind, but the results of Yandow and Klein (1986) do not support this hypothesis: they found no lasting effect of solution Al concentrations up to 3300 μmol/L on the nitrate reductase activity of red spruce root tips in a solution culture study. We are currently pursuing this issue, and we hope to offer some alternative hypotheses in the near future.

Foliar Ca and Mg levels are also relatively low in both the Smokies and Whiteface sites. Given the studies by Thornton et al. (in press) this could be, at least part, a result of inhibition of the uptake of these cations by Al. Friedland et al. (in press) compared the results from six studies of mature red spruce trees, including their own study in Vermont and at Whiteface Mountain in New York. They found that Mg concentrations in high-elevation foliage in Vermont and New York are lower than those at any other site reported in the literature. In comparing red spruce foliar chemistry given in Table 3, we find that at Whiteface, P and Mg are low compared with other values reported for red spruce. At the Smokies sites, N and Ca are low compared with other values reported for red spruce. We do not believe that these findings suggest nutrient deficiencies, yet we feel they may be indicative of an additional stress to the trees.

Conclusions

At this early stage in the study, we can only draw limited conclusions from the preliminary data sets now available. Some interesting comparisons have arisen however, when the chemial composition of the soils and soil solutions from these four sites were compared. It is useful to put this summary of our current information in the context of the capacity-vs-intensity factors discussed by Reuss and Johnson (1986). Specifically, we can consider the chemical compositions of these soils (exchangeable cations, total N, etc.) as capacity factors that change relatively slowly over time, and the chemical compositions of the soil solutions as intensity factors, that change rapidly (i.e., with the introduction of mobile anions).

In terms of the capacity factors, we note the soils from all four sites are extremely acid, with base saturations in mineral soils often less than 10% (by the sum-of-cations method). The Findley Lake site in the Cascade Mountains is relatively unpolluted (Johnson et al. 1977); thus, the acidity of that soil is due entirely to natural processes (i.e., organic and carbonic acid leaching, nutrient uptake by plants, humus formation). The fact that the Findley Lake soil is no less acid than the Smokies or Whiteface soils demonstrates the potency of these natural acidification processes and the potential mistake of assuming that extremely acid soils in polluted regions (such as those in the Smokies and Whiteface sites) were acidified by atmospheric deposition.

In terms of the intensity factors, on the other hand, we note that the Smokies sites have the greatest soil solution anion concentrations and therefore, the greatest total cation concentrations. Exchange relationships dictate that the concentration of Al will increase to a greater extent than the concentrations of other major cations in soil solution--specifically, by the 3/2 power of Ca and Mg concentrations and by the third power of H^+, K, and Na concentrations (Reuss 1983); thus, we see that the differences in cation concentrations among the four sites are far greater for Al than for the other cations (Table 2). These same exchange equations predict that soil solution Al concentrations in the other sites should increase to levels approximately equal to those currently found in the Smokies sites if the anion concentrations should increase, since soil base saturations (the capacity factors) are similar.

Thus, we are gratified to find patterns of soil and soil solution chemistry that are consistent with theory, offering us the hope of making realistic predictions. Our future efforts, in addition to pursuing further the issues of N uptake and potential Al toxicity noted above, will include predictions of changes in soil solution and nutrient cycling patterns through simulation modeling.

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Connections Between Forest Decline and Element Fluxes in Forest Ecosystems in NE-Bavaria, FRG

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Introduction

Terrestrial ecosystems are characterized by compensating, alternating effects between autotrophic primary producers and heterotrophic secondary consumers. If these element transformations would compensate each other exactly the ecosystem would be in a steady state. Then, a closed ion cycle of nutrients exists within the system, while uncharged substances like CO_2, O_2, and H_2O are taken out of the atmosphere and returned to it. When judging state and development of forest ecosystems it is necessary to know whether they are in steady state and if not, how far they are away from steady state. This decision can be made by measuring element fluxes and calculating the ecosystem budget. Steady state then means that input and output of elements are equal. To get a certain impression of the development of a forest ecosystem it is very important to have long-term measurements, because short-term fluctuations can influence results heavily (Ulrich 1983). Additionally, evaluation of element fluxes and ecosystem balances, respectively, often indicate in which compartment of an ecosystem ecologically important processes are going on (Meiwes et al. 1986, Khanna et al. 1987). Therefore these budgets are essential to the design of process studies and experiments.

Site Description

Geology and Geomorphology

In northeastern Bavaria, on the Czech frontier, the wide, massive peaks and ridges of the Bavarian Forest, the Oberpfälzer Wald, the Fichtelgebirge and the Franconian Forest, are to be found. These are the basic mountains of northeastern Bavaria. They are the remains of a geologically very old Palaeozoic mountain range, reaching heights of just over 1000 m in the Fichtelgebirge (Schneeberg 1051 m).

Geomorphologically, this is a tropoidal insular range that was exposed to extensive weathering with resultant surface formation in the Tertiary. Thus, some of the existing rocks (granite, gneiss, phyllite, slate) acquired large kaolinite deposits, which today form the basis of the northern Bavarian porcelain industry. During the Quarternary, many valleys were formed and solifluidal soil movement occurred. The result on the one hand were deep wedge-shaped valley clefts and, on the other, highly compressed solifluidal covers with bizarre labyrinths of rock exposed to view on the summits (Kosseine near Wunsiedel).

Climate

The Fichtelgebirge form the weather divide between the Atlantic and the Black Sea. In addition, they represent a climatic boundary. Thus, the more exposed slopes on the west, including summits such as the Schneeberg, Ochsenkopf and Waldstein, have a strongly characterized Atlantic climate with average annual precipitation of 1000 to 1200 mm and mean annual temperature between 4.5 and 6.0° C. The eastern part, in the area of the Selb-Wunsiedler Bight, on the other hand, is already markedly continental in character (average annual precipitation 600 mm, cold winters with icy east winds and a short vegetation period). There are up to 200 days with fog. The main wind directions are east (30%), northwest (17%) and southwest (13%). Because of its topographic and geomorphological characteristics the Fichtelgebirge is a major barrier for the predominant west and east winds, but also for air currents from the north and south. This is probably of significance as regards forest decline.

Forest Decline

Since the beginning of 1980, increasing damage has been observed on a wide scale in all species of tree except fir. For instance, in the period 1983-84 the area of Bavaria with no signs of damage declined by 10% to 43%, while the moderately damaged stands increased by 13%. Particularly, marked damage was found in the Fichtelgebirge, the Franconian Forest and the Steinwald. The Forest Decline Survey of 1984 found the following: More than 60% of the main species of tree, the spruce (85% share by area) shows damage of some type. A quarter of all spruces are slightly damaged, 38% are moderately damaged and 5% are severely damaged or dead. In pine, which only covers 10% of the area, the damage is less marked. Here 41% of the area was rated as having damage of category 1.

Investigation Sites

The research site Oberwarmensteinach is situated on a west-exposed slope of the Fichtelgebirge at an altitude of 760 m, the site of Wülfersreuth on a west-facing slope at 680m. The soils at the sites are either podzols (Tables 1a, b) or podzolic brown earths (Tables 2a, b) derived from matamorphic rocks such as phyllite. At the two sites, the current vegetation is primarily Norway spruce about 20 to 40 years old. Originally, the forests contained mixed stands of Norway spruce, European beech, and silver fir. These forests were largely destroyed by cutting during the Middle Ages. Systematic silvicultural management has been in effect for the past one hundred years.

Precipitation Input of Ions

Precipitation input of elements represents one main part of the element budget in terrestrial ecosystems. The amount of single ion inputs is often provided by anthropogenic, atmospheric pollution, especially in highly industrialized areas (Ulrich et al. 1979, Stumm et al. 1983). Therefore measurements of ions which

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dominate the ion charge balance, and of heavy metals, yield important information on the inorganic pollution climate of the study area.

Mean values of precipitation input into two young spruce stands (20 to 40 years old) in highlands of NE Bavaria, called Fichtelgebirge, for a two year measuring period are shown (Figures 6-10). Maximum concentrations for this period are also given (Figures 6-9). Comparing both sites, Oberwarmensteinach and Wülfersreuth, no significant differences could be found for deposition of macroelements and heavy metals.

A comparison of the deposition situation in the Fichtelgebirge with other German sites is presented (Tables 3a, b and Tables 4a, b). The mean concentration results (Tables 3a, b) show lower mean pH-values (pH 4.2) and higher SO_4-S concentrations (2.6 mg/l) in the Fichtelgebirge than on the other Bavarian sites. Mainly the low pH-minimum values (pH3.1) are remarkable in their ecological consequences (Fritsche 1987). High heavy metal concentrations underline the notable, anthropogenic pollution of the investigated area.

For ecological interpretations, it is also necessary to discuss deposition fluxes (Figures 10-18). Differences of fluxes between individual halfyears are primarily caused by different amounts of precipitation. Again no significant differences could be found between the input into spruce stands in Oberwarmensteinach and Wülfersreuth. The low variation of proton fluxes in Bavaria with the exception of Schönbuch are shown (Tables 4a,b). Accordingly, the variation of the main acidifiers, SO_4-S and N-compounds, is also low. The Solling area in N-Germany (IBP-project) is characterized by a higher proton input and the highest Pb-input of the listed sites. The Solling stand is composed of 100-year-old spruces, a very important difference to the stands in the Fichtelgebirge in regard to deposition fluxes, as shown in Differences between young and old spruce stands section.

Canopy Budgets of Spruce Stands

Ecological studies of recent years have shown important hydrochemical changes of rainwater during the passage through forest canopies (Hoffman et al. 1980, Cronan and Reiners 1983, Skiba et al. 1986). One main cause of these changes is the washing away of intercepted ions from canopy surfaces. Interception deposition is the sum of impaction of aerosols and droplets

Table 1a.--Important chemical parameters of the podzol in Oberwarmensteinach

Horizon	Depth	pH	Total Contents					Exchangeable Ions			
			N	C	K	Ca	Mg	K	Ca	Mg	Al
	cm				g/kg				meq/kg		
Aeh	0 - 18	3.2	9.1	17	38	0.2	2.1	1.1	1.2	0.26	63
Bs	18 - 38	3.8	7.9	15	21	0.4	2.2	1.1	1.1	0.10	60
BvCv1	38 - 54	4.2	5.6	6	34	0.9	1.2	1.0	1.0	0.10	15
BvCv2	54 - 76	4.2	5.6	6	34	0.9	1.2	1.0	1.0	0.10	15
Cv	76 +	4.4	9.4	2	51	0.3	2.1	0.8	0.9	0.02	13

Table 1b.--Important physical parameters of the podzol in Oberwarmensteinach

Horizon	Depth (cm)	Grain Sizes			Stones (%)	Texture	dB	dF	pF				
		% S	% U	% T			(g/cm³)		TPV (Vol%)	1.8 (Vol%)	2.5 (Vol%)	4.2 (Vol%)	ks (cm/d)
Aeh	0 - 18	25.5	59.4	15.1	41.6	slU	1.20	2.46	51.5	18.4	21.2	11.9	620.6
Bs	18 - 38	23.1	61.8	15.1	41.8	slU	1.15	2.68	57.0	21.7	18.0	17.3	389.2
BvCv1	38 - 54	33.3	56.8	9.9	61.2	slU	1.44	2.73	47.3	23.5	14.4	9.4	286.0
BvCv2	54 - 76	37.1	54.3	8.6	53.6	slU	1.49	2.70	45.0	22.9	11.9	10.2	562.5
Cv	76 +	31.1	60.6	8.3	73.3	slU	1.47	2.73	46.2	22.5	13.7	10.0	354.7

Table 2a.--Important chemical parameters of the podzolic cambisol in Wülfersreuth

Horizon	Depth	pH	Total Contents					Exchangeable Ions			
			N	C	K	Ca	Mg	K	Ca	Mg	Al
	cm		g/kg					meq/kg			
Aeh	0 - 5	2.8	3.0	104	23	0.4	1.9	1.5	11.0	0.76	126
Bv	5 - 23	3.7	0.6	7	26	0.5	2.5	0.7	2.8	0.25	60
BvCv1	23 - 60	4.1	0.6	4	31	0.6	3.6	0.8	2.5	0.10	26
II BvCv2	60 - 110	4.3	0.5	4	31	0.7	3.6	0.8	1.2	0.04	25
II Cv	110 +	4.1	0.5	2	38	0.8	5.2	1.3	1.9	0.30	35

Table 2b.--Important physical parameters of the podzolic cambisol in Wülfersreuth

Horizon	Depth (cm)	Grain Sizes % S	% U	% T	Stones (%)	Texture	dB (g/cm³)	dF	pF TPV (Vol%)	1.8 (Vol%)	2.5 (Vol%)	4.2 (Vol%)	Kf ks (cm/d)
Aeh	0 - 5	21.9	73.9	4.2	43.7	SU	0.86	2.47	65.2	24.3	19.6	21.3	810.2
Bv	5 - 23	14.2	63.3	22.5	43.7	slU	1.16	2.69	56.7	28.2	14.8	13.7	965.5
BvCv1	23 - 60	29.5	62.4	8.1	67.9	slU	1.43	2.72	47.5	22.8	14.7	10.0	701.3
II BvCv2	60 - 110	31.1	61.0	7.9	51.3	sU	1.36	2.71	49.8	22.7	20.4	6.7	617.3
II Cv	110 +	70.1	28.6	1.3	64.6	uS	1.44	2.68	46.4	11.5	28.1	6.8	79.0

Table 3a.--Mean values of selected element concentrations in precipitation (mg/l) in Oberwarmensteinach (O) and Wülfersreuth (W) for the period July 1984 to June 1986 in comparison to other German sites (Al and P in μg/l)

Element	O	W	Solling(1)	Bodenmais(2)	Taubenberg(2)	Schönbuch(3)
pH	4.18	4.21	4.08	4.5	4.5	4.33-4.66
Ha	0.74	0.83	0.79	0.5	0.5	0.43-0.66
K	0.71	0.62	0.37	0.5	0.2	0.3-0.6
Mg	0.20	0.22	0.20	0.1	0.1	0.09-0.11
Ca	0.88	1.04	1.20	0.6	0.6	0.5-1.2
MM-M	0.96	1.07	1.23	0.8	0.7	0.59-0.73
MO$^{4}_{3}$N	1.10	1.17	0.81	0.6	0.5	1.5-2.3
SO$^{4}_{4}$S	2.65	2.59	2.70	1.9	1.5	0.9-1.1
Cl^{4}	1.23	1.32	1.80	1.2	0.8	0.7-1.0
PO$_4$-P	50.9	60.6	-	-	-	-
Al	95.1	113.2	120.0	-	-	0.0

Table 3b.--Mean values of selected heavy metal concentrations in precipitation ($\mu g/l$) in Oberwarmensteinach (O) and Wülfersreuth (W) for the period July 1984 to June 1986 in comparison to other German sites

Element	O	W	Solling(4)	Schwarzwald(5)	Schönbuch(3)
Zn	175	178	142	15	7-20
Cd	0.9	1.1	1.5	0.16	n.n.
Pb	16	15	27	7.6	n.n.-9
Cu	59	45	23	3.3	< 7

n.n. not detectable
(1) mean values 1969-1979 in ULRICH et al. (1979)
(2) mean values 1980/81 in DUNKL et al. (1987)
(3) mean values 1978-1982 in BUECKING et al. (1986)
(4) mean values 1974-1979 in MAYER (1981)
(5) mean values 1982-1985 in MIES (1986)

Table 4a.--Selected element fluxes ($g/m^2 \times 10^{-1}$) with precipitation input in Oberwarmensteinach (O) and Wülfersreuth (W) in 1985 in comparison to other German sites

Element	O	W	Solling(1)	Bodenmais(2)	Taubenberg(2)	Schönbuch(3)
H^+	0.54	0.46	0.79	0.5	0.4	0.15-0.37
K	5.88	4.16	3.7	7.2	2.6	2.1-4.4
Ca	6.55	6.98	10.0	8.9	8.4	3.5-9.4
Mg	1.53	1.48	1.8	1.6	1.6	0.6-0.9
M	16.5	18.2	24.3	21	17	5.5-8.2
SO_4-S	21.54	19.08	23.5	28	22	15-23

only NH_4-N and NO_3-N

Table 4b.--Selected heavy metal fluxes ($mg/m^2 \times 10^{-1}$) with precipitation input in Oberwarmensteinach (O) and Wülfersreuth (W) in 1985 in comparison to other German sites

Element	O	W	Solling(4)	Schönbuch(3)	Hils(5)
Zn	1220	1150	1377	52-370	190
Cd	10.3	13.5	15.86	2	1.7
Pb	184.3	170.0	285	-	116
Cu	711.3	563.2	236	-	26.5

(1) - (4) see legend Table 1b
(5) in Ulrich et al. (1986)

(fog and cloud droplets) and of gas absorption. Receptor surfaces, in our case needles and bark, strongly influence the deposition rate by their size, type of surface and chemical composition. The other factor, which mainly changes rainwater chemistry, is the totality of all biogeochemical reactions of rainwater and interception deposition with the tree's biological surfaces (Cronan and Reiners 1983).

Rates of interception deposition on forest canopies and various processes are calculated with a confirmed approach of Ulrich (1983). The approach rests on the measurement of precipitation input, i.e. wet deposition and throughfall. Flux balance equations are used to account for sink and source terms of the canopy. A so-called interception factor is calculated with the inert Cl-ion and transferred to interception deposition of other main cations. Using this concept it is possible to calculate cation leaching of leaves, SO_2-and gaseous proton input as well as proton buffering in the canopy. But it is important to remember that this approach can be used only for long-term budgets and not for interpretation of daily or weekly deposition processes (Ulrich 1981a).

Element Fluxes in Canopies of Young Spruces

Canopy budgets of the investigated stands are presented only for SO_4-S, protons and the base cations K, Ca and Mg, which are considered to be the most important ions in forest decline processes. The different listed deposition and canopy processes of SO_4-S and H^+ on one control plot (plot 1) and two fertilization plots in Oberwarmensteinach and Wülfersreuth. The same results for K, Ca and Mg are presented (Figures 3-5). Plot 2 is fertilized with 100 g/m² $MgSO_4$ x H_2O and plot 5 with 1000 g/m² $CaCO_3$ x MgO (information on plant nutrition and soil chemistry on fertilization plots by Kaupenjohann 1989).

SO_4-Sulfur

Precipitation and gaseous sulfur input in Oberwarmensteinach are equivalent, while the particulate deposition is distinctly smaller than the other inputs (Figure 1). Gaseous and particulate deposition over the half-year periods are staffered over the plots, depending on different stand structure and so caused different deposition probabilities (Ruck and Schmitt 1986). Bulk deposition with throughfall is similar on all plots and does not show the known differences between summer and winter (Matzner and Ulrich 1984). Wülfersreuth is characterized by significantly lower SO_4-input values ($p<0.05$) with throughfall, e.g. 2.9 g/m² in 1985 and 4.2 g/m² in Oberwarmensteinach. The higher deposition into the damaged spruce stand is mainly caused by significantly higher SO_2-input ($p<0.05$) into this stand than into the healthy one in Wülfersreuth. This ecologically important fact can be caused by a different pollution climate on the single sites and/or by the different geographic position of the spruce stands. While the 20- to 40-year-old trees investigated in Oberwarmensteinach are located on top of a hill, the stand in Wülfersreuth is situated between 100-year-old spruces in the middle of a slope.

Protons

The importance of the gaseous H^+-input compared to precipitation and particulate deposition is illustrated (Fig. 2). In Oberwarmensteinach the gaseous input over two years is even higher than bulk deposition with the throughfall. Accordingly, canopy buffering, calculated as the difference between total and throughfall deposition, is considerable. It is higher than the precipitation input on all plots. Total deposition on plot 1 amounted to 0.16 g/m² in 1985. Gaseous proton input in Wülfersreuth was significantly lower ($p<0.05$) than in Oberwarmensteinach. Consequently, total deposition and canopy buffering are also lower ($p<0.05$). Total deposition on plot 1 amounted 0.09 g/m² in 1985. The mistake of calculating proton input by using pH-values of throughfall can also be estimated (Fig. 2). Deposition amounted to about 0.1 g/m² in 1985, using the pH-values of throughfall for calculation. The real input, which considers proton buffering in the canopy, is 0.16 g/m². Therefore the input is underestimated by more than 50% by the throughfall proton content. Hantschel (1987) could show these mistakes for several Bavarian sites.

Several studies have shown an increase of pH-values in the throughfall compared to the precipitation due to proton buffering in the canopy (Cronan and Reiners 1983). In the investigated spruce forests, this phenomenon cannot be analyzed during the two year measuring period. The variation of canopy buffering over the plots depends on the different deposition situation (Ruck and Schmitt 1986) and on the physiological and nutrient status of the trees (Skiba et al. 1986). The high buffering rate on all plots in the first half of 1986 is very remarkable. It is probably caused by very high SO_2-levels, 739 $\mu g/m^3$ were measured in February 1986 (Hantschel 1987).

Concerning canopy buffering, it is fundamental to consider an equivalent release of protons into the rhizosphere. Therefore, canopy buffering cannot relieve the ecosystem, but confronts it with protons in the sensitive rhizosphere region. Several authors have postulated this buffering mechanisms (Matzner and Ulrich 1984, Reuss and Johnson 1986). Leonardi and Flückiger (1988) proved it with laboratory experiments. Kaupenjohann et al. (1988) could also show the equivalent acidification of nutrient solutions of spruce seedlings after spraying them with acidic mist.

Potassium, Calcium and Magnesium

Using the canopy budget model of Ulrich (1983), the base cations K, Ca, and Mg are exchanged against protons in the process of canopy buffering. This process causes leaching and, therefore, a significant increase of ion concentration of these base cations in throughfall samples, in addition to dry deposition.

K-leaching rates on plot 1 are twice as high as the precipitation input (Fig. 3). Consequently, throughfall deposition amount to about 3 g/m² in 1985. The fraction of particulate deposition on this size is negligibly small. The healthy spruce stand in Wülfersreuth is characterized by significantly lower ($p<0.05$) K-leaching rates than the damaged spruces in Oberwarmensteinach. Therefore, only 1.6 g/m² were deposited with throughfall in 1985. The influence of fertilization on K-leaching is also different between both stands. While the leaching of potassium is distinctly reduced on all fertilized plots in Oberwarmensteinach, no effect was observed in Wülfersreuth.

Matzner (1984), as well as Leonardi and Flückiger (1988), reported high K-leaching rates in damaged forest stands. Skiba et al. (1986) refer to the interdependency of potassium leaching and canopy buffering. Thus, the different leaching rates in Oberwarmensteinach and in Wülfersreuth may be a result of the different canopy buffering rates in those canopies. The differences in K-leaching can also be influenced by the different nutrition status of spruces. Spruces with lower leaching rates in Wülfersreuth show better base cation contents than trees in Oberwarmensteinach (Kaupenjohann et al. 1987). Consequently, K-leaching rates in Oberwarmensteinach could be reduced by improving the nutrient levels, mainly Mg, on the fertilization plots, while in Wülfersreuth, the lack of nutritional differences prevent different leaching rates on the single plots.

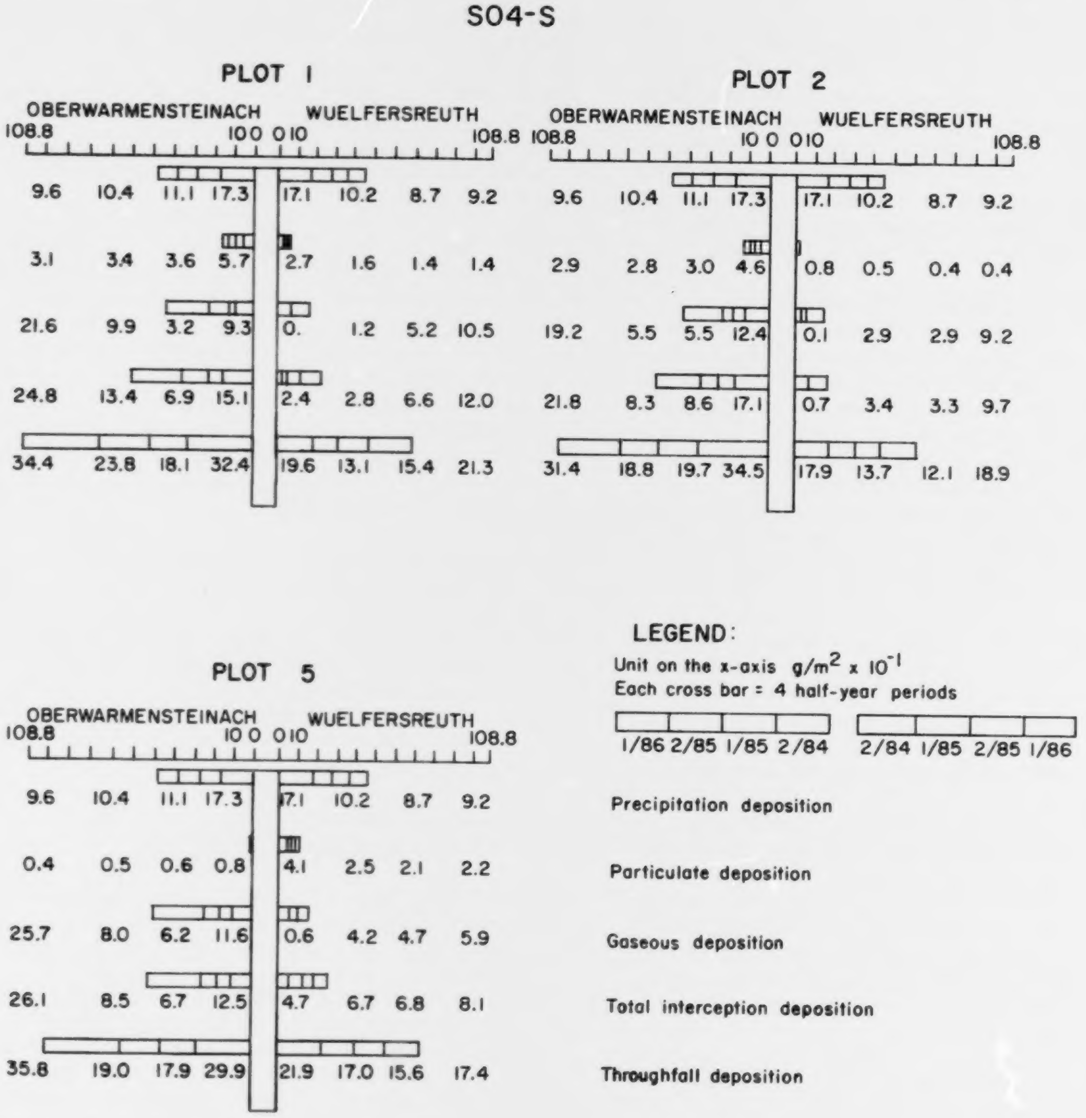

Figure 1.--Canopy balance of SO_4-S (g/m^2 x 10^{-1}) on plot 1, 2, and 5 in Oberwarmensteinach and Wülfersreuth for the period July 1984 to June 1986.

Ca-losses of needles in Oberwarmsteinach are in the range of precipitation input (Fig. 4) and throughfall deposition amounted to 1.5 g/m^2 in 1985. No differences between Ca-leaching on the single fertilization plots can be shown on this site, not even on the limed plot. In Wülfersreuth, which is characterized by a throughfall deposition of 1.1 g/m^2, Ca-leaching rates are significantly lower ($p < 0.05$) than in Oberwarmensteinach, with the exception of plot 5.

The described range of Ca-leaching rates are in agreement with the better needle nutrition levels in Wülfersreuth. Only high leaching rates on plot 5 in Wülfersreuth do not correspond.

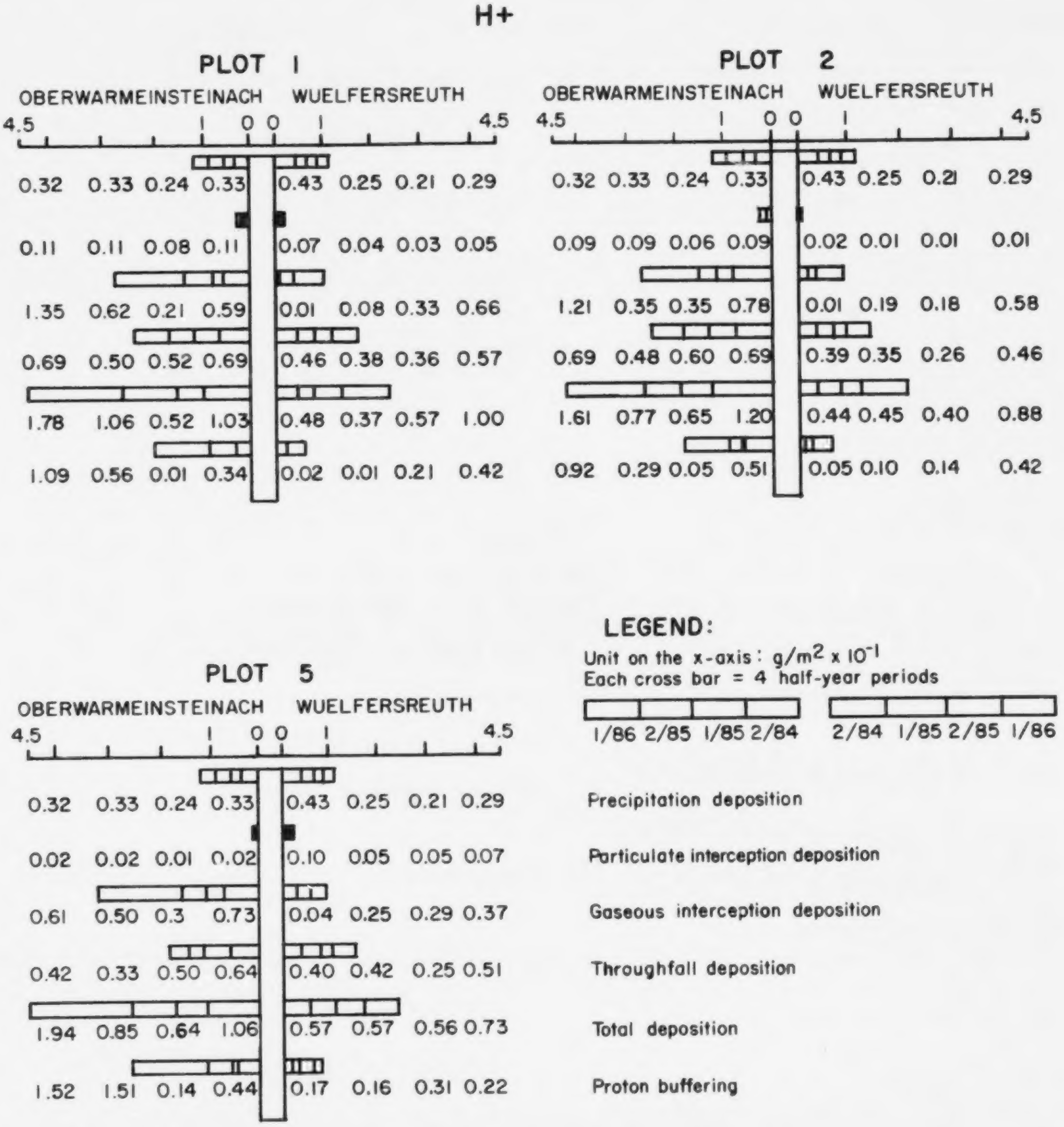

Figure 2.--Canopy balance of protons (g/m^2 x 10^{-1}) on plot 1, 2, and 5 in Oberwarmensteinach and Wülfersreuth for the period July 1984 to June 1986.

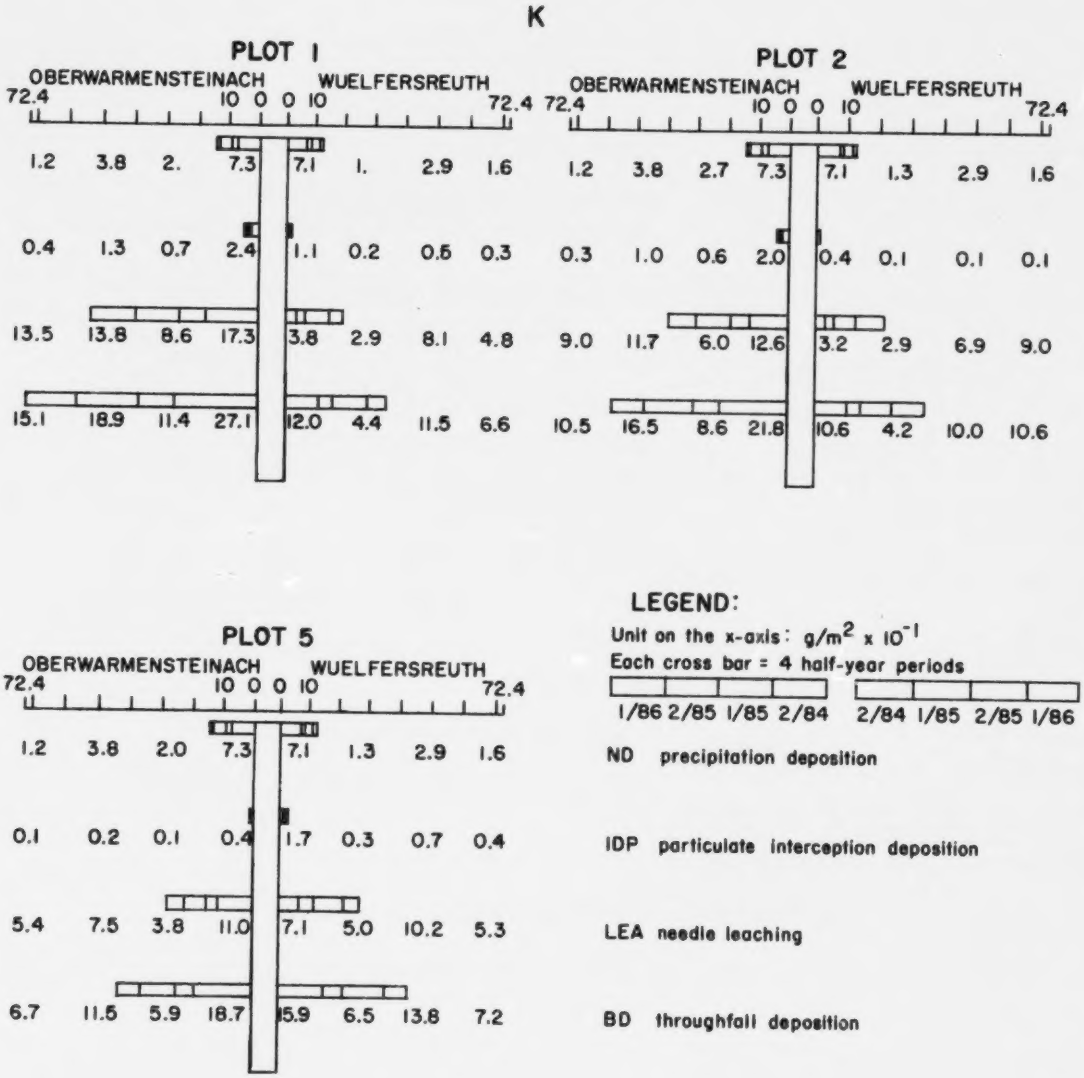

Figure 3.--Canopy balance of K (g/m^{-2} x 10^{-1}) on plot 1, 2, and 5 in Oberwarmensteinach and Wülfersreuth for the period July 1984 to June 1986.

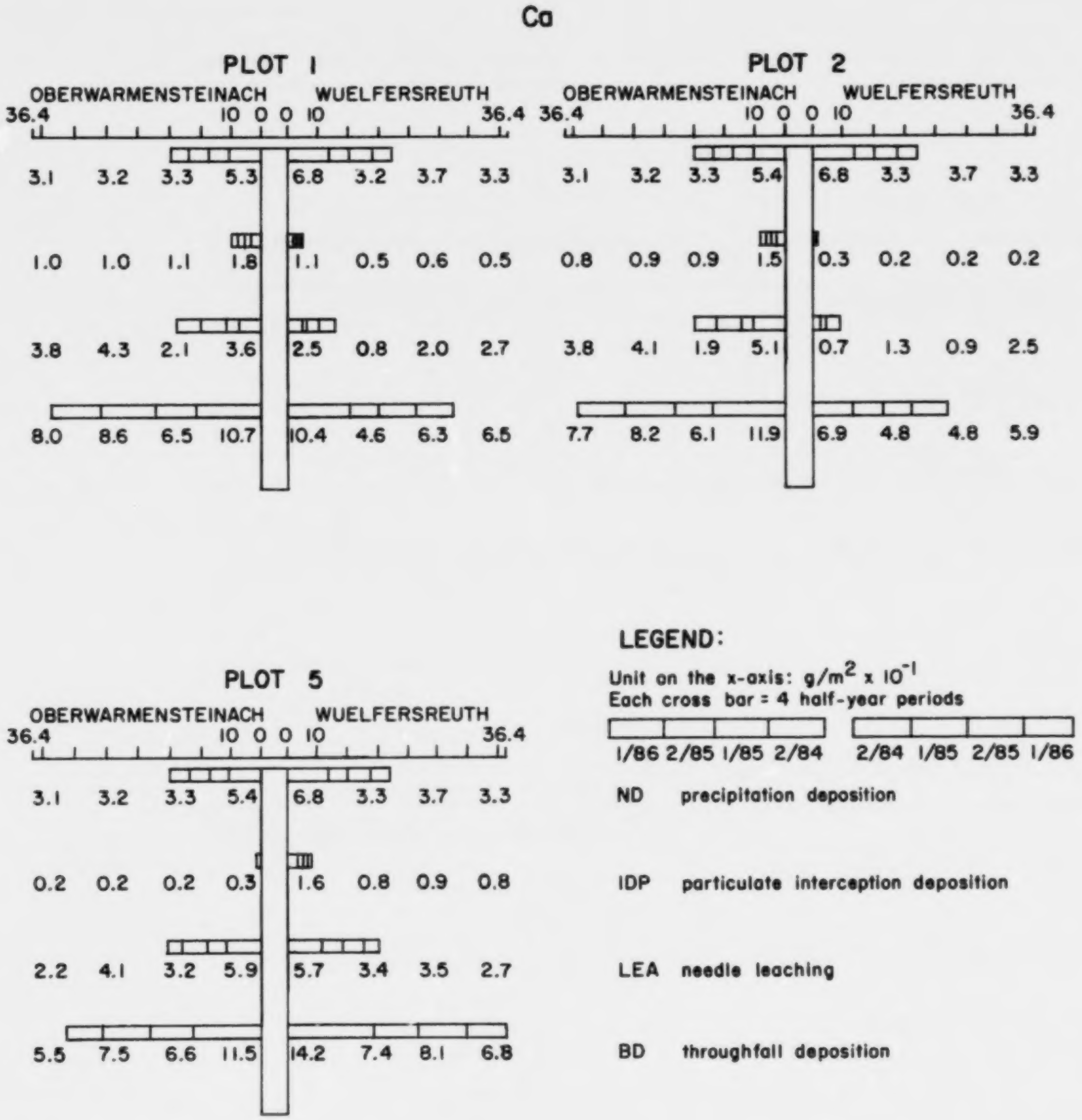

Figure 4.--Canopy balance of Ca (g/m^2 x 10^{-1}) on plot 1, 2, and 5 in Oberwarmensteinach and Wülfersreuth for the period July 1984 to June 1986.

Significantly higher Mg-leaching rates ($p < 0.05$) occurred on fertilization plots in Oberwarmensteinach compared to the control plot (Fig. 5). On the latter, Mg-leaching rates amount to about half of precipitation input and throughfall deposition was 0.23 g/m^2 in 1985. In Wülfersreuth, significantly less Mg is leached on plot 1 to 4 than in the damaged stand in Oberwarmensteinach ($p<0.05$), while the situation is the opposite on plot 5. The differences of the Wülfersreuth fertilization plots against the control plot (throughfall deposition 0.21 g/m^2 in 1985) were statistically significant ($p<0.05$).

Mg-leaching fluxes generally seem to increase after Mg-fertilization. The differentiation between both investigated stands could be caused by more severe needle damage in Oberwarmensteinach, in spite of the revitalizing fertilization.

It is important to consider the much lower Mg contents in the needles of spruces in Oberwarmensteinach than in Wülfersreuth (Kaupenjohann et al. 1987). Plot 5 in Wülfersreuth, with its high Ca- and Mg-leaching rates, is an exception, which perhaps indicates invisible, direct needle damage on this plot.

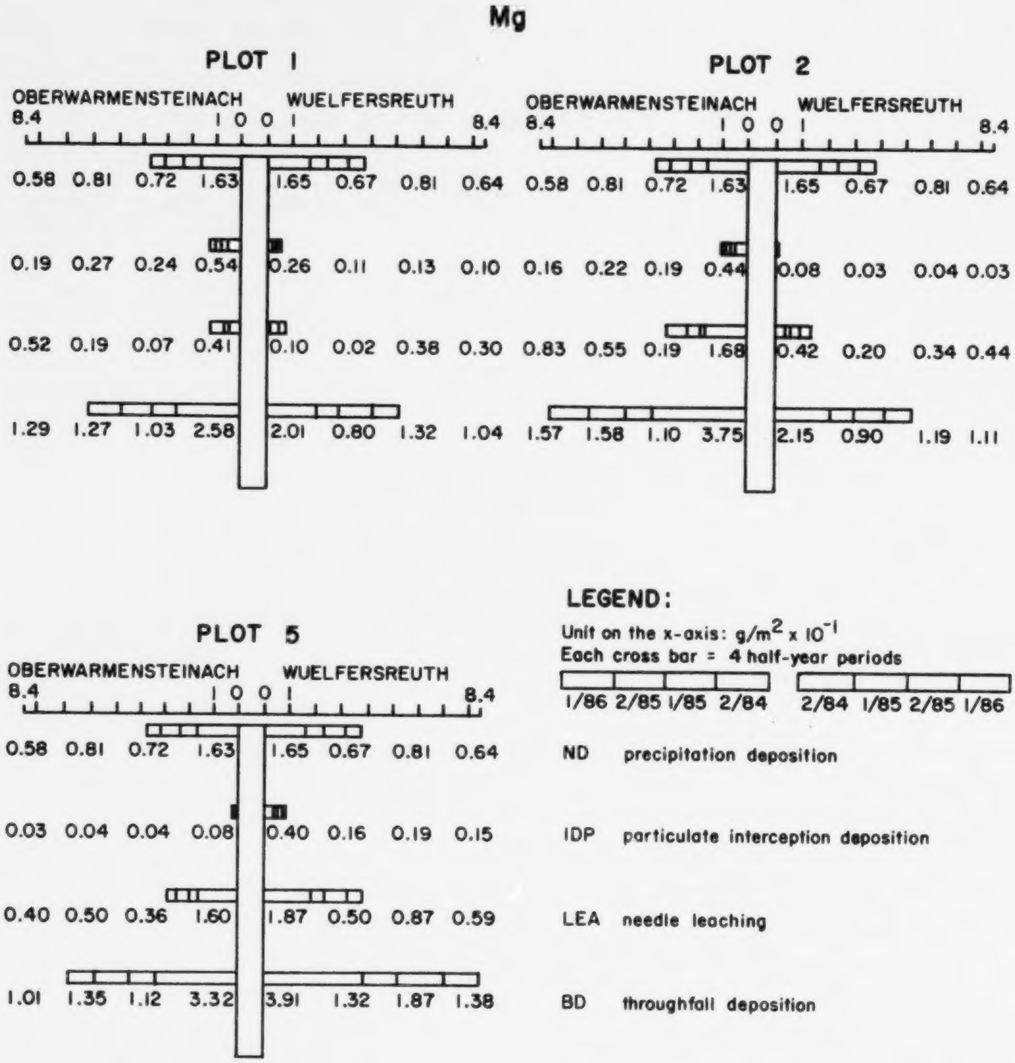

Figure 5.--Canopy balance of Mg (g/m^2 x 10^{-1}) on plot 1, 2, and 5 in Oberwarmensteinach and Wülfersreuth for the period July 1984 to June 1986.

Mengel et al. (1987) judging leaching rates of base cations as too small to accelerate forest decline caused by nutrient deficiency. Considering the experiments of Zöttl and Mies (1983), Zöttl and Hüttl (1985), and Kaupenhjohann et al. (1988), decline of spruces seems to be intensified by needle leaching of Mg on very Mg-poor stands.

Nitrogen

The nitrogen compounds NH_4 and NO_3 are not split in different deposition fluxes, because some processes are happening with these compounds in the canopy which cannot be calculated with Ulrich's model, e.g. N-assimilation by trees. Interactions with the canopy can change the chemical form of nitrogen compuonds. Therefore, N-input is discussed only on the basis of precipitation and throughfall deposition.

Changes in NH_4-N- and NO_3-N-fluxes in the canopy are presented (Fig. 16 and 17). In Oberwarmensteinach, a more or less intensive increase of nitrogen fluxes is measured in throughfall samples of the half-year periods which range from 18 to 83% (NH_4-N: 1.4 g/m^2/1985 on plot 1) and 19 to 37% (NO_3-N: 1.0 g/m^2/1985 on plot 1) of the precipitation fluxes on the single plots. Wülfersreuth is characterized by a nearly unchanged throughfall deposition of NO_3-N (1.1 g/m^2/1985 on plot 1) compared to precipitation input and an insignificant decrease of NH_4-N (0.8 g/m^2/1985 on plot 1). The more distinct increase of the nitrogen content in throughfall samples from Oberwarmensteinach could be a result of higher gaseous input of NH_3, NO_3, and/or HNO_3 than in Wülfersreuth. This site differentiation could be proven for SO_2 (Hantschel 1987). Furthermore, some ecosystem studies indicate that a major part of N-deposition may be assimilated in the canopy and does not reach the throughfall rain gauges (Matzner 1984). Therefore N-input values calculated with throughfall data represent a conservative estimate of the real N-input into a forest ecosystem.

Heavy Metals

High variations of Zn-, Cd-, Pb-, and Cu-input on both investigation sites were measured (Fig. 19). Consequently, no significant differences between input rates of different heavy metals, single half-years or single plots can be shown (Hantschel 1987). Generally, deposition of these ions, especially of Cu, is high, corresponding to the bad pollution situation in NE-Bavaria. Throughfall input again depends on canopy processes, which change precipitation input specifically for each heavy metal. While Zn- and Cd-fluxes are mostly increased beneath the canopy (280 mg Zn/m^2/1985 and 0.79 mg Cd/m^2/1985 on plot 1 in Oberwarmensteinach, and 62 mg Zn/m^2/1985 and 0.79 mg Cd/m^2/1985 on plot 1 in Wülfersreuth), Pb- and Cu-input with the throughfall is always lower than with precipitation (11 mg Pb/m^2/1985 and 21 mg Cu/m^2/1985 on plot 1 in Oberwarmensteinach and 8 mg Pb/m^2/1985 and 33 mg Cu/m^2/1985 on plot 1 in Wülfersreuth). Zöttl (1985) described similar behavior of heavy metals in the Black Forest.

The increase of Cd-fluxes during passage through the canopy is probably caused by the washing off of particulate deposition. Zinc increase, however, is supposed to be mainly an effect of needle leaching (Mengel et al. 1987). Calculations showed that Zn-leaching on our plots is low during the two year measuring period, compared to laboratory results (Mengel et al. 1987). The different reaction of Cu and Pb compared to Zn and Cd is determined by their tendency to form organic complexes. These compounds can form in the canopy and be fixed on needle or bark surfaces, reducing the heavy metal concentrations in throughfall. They can be washed off again by highly acidified precipitation events (Mayer 1981).

Differences between young and old spruce stands

The adjacent 80- to 100-year-old spruce stands in Oberwarmensteinach do not show any needle yellowing like the Mg-deficient young spruces, but more or less severe needle loss (silver tinsel symptom). To get first indications of these different damage symptoms on the same site and the same substratum some comparative input measurements were done in the old spruce stand to calculate single deposition amounts using Ulrich's model (1983).

Fluxes of sulfur, protons, potassium, calcium and magnesium in the old stand from August 1985 to July 1986 are presented (Table 5). Additionally, the percentage of fluxes in the old stands compared to the fluxes in the young stands (= 100%) are listed. All element fluxes under the old spruces are higher than the respective fluxes under young spruces. The particulate deposition increases by a factor of 5. Nevertheless SO_2-deposition remains the most important factor for sulfur input because it causes the main fraction of SO_4-content in the throughfall. Proton deposition is dominated by the gaseous input by solution of SO_2 (Ulrich 1983). It is remarkable that canopy buffering in the old stand is not higher than in the young one. Thus, proton content in the throughfall increases by 43% compared to the young stand and reaches values measured by Matzner and Ulrich (1984) in old spruce stands (see Table 4a). Leaching rates of K, Ca, and Mg remain higher than particulate deposition, although they increase. But there is a different increase of these three base cations in the throughfall, which is probably caused by a specific change in their leaching behavior. While K-fluxes hardly increase compared to the young stands, Ca- and Mg-leaching rates in the old stand are two to three times higher.

These results accentuate the importance of the filter capacity of trees for particulate and gaseous deposition. Additionally, the measurements illustrate different hydrochemical changes of rainwater during canopy passage, although the trees are influenced by the same precipitation and the same weather situation. These results explain why we have to expect different soil chemical reactions on the same substrate, depending on canopy shape and stand age (Kaupenjohann and Hantschel 1987, Kaupenjohann et al. 1989). Based on these data, different influences on the health of trees on the same substratum can be understood (Kaupenjohann 1989).

Table 5.--Canopy budget ($g/m^2 \times 10^{-1}$) of a 100-year-old spruce stand in Oberwarmensteinach for the period August 1985 to July 1986 in comparison to the young stand on plot 1 (100% = canopy balance values on plot 1)

	S		H		K		Ca		Mg	
Item	flux	%	flux	%	flux	%	flux	%	flux	%
ID_p	25.8	496	0.89	494	6.0	500	7.7	513	1.59	497
ID_g	34.4	122	2.15	122	-	-	-	-	-	-
BD	77.4	153	2.00	220	26.3	132	27.0	216	3.52	165
TD	-	-	3.63	143	-	-	-	-	-	-
PA	-	-	-	-	16.3	111	19.3	327	1.93	257
HPU	-	-	1.63	101	-	-	-	-	-	-

ID_p particulate interception deposition
ID_g gaseous particulate deposition
BD throughfall deposition
TD total deposition
PA leaching
HPU proton buffering

Fluxes of elements through soils

From an ecological point of view it is very important to investigate transport processes and element output with seepage water. On the one hand, nutrient uptake, which is one of the most important processes for productivity and stability of an ecosystem, takes place out of the percolating soil solution. On the other hand, the percolation water beneath rooted horizons represents a quantitatively and qualitatively important influx to groundwater. Especially nitrate levels in percolation water were analyzed in this context (Kreutzer and Weiger 1974). Judging soil reactions caused by ecosystem internal or external proton loads also presumes knowledge of quantity and quality of seepage water. In recent years, many ecosystem studies were done on soil solution characterizations and changes by environmental influences (Matzner and Ulrich 1981, Stahr et al. 1983, Nilsson et al. 1983, Matzner et al. 1984, Knight et al. 1985, Hauhs 1985, Reiter et al. 1986, Bücking et al. 1986).

Selected ion concentrations in different soil depths

Figures 6-10 present two year mean values and maximum values of selected ion concentrations in soil solution sampled by litter lysimeters and suction cups in three soil depths are shown (Figures 6-10). Ions of the ion balance not discussed here are presented by Hantschel (1987).

Protons

An important distinguishing feature of both sites are the lower pH-values of the soil solution in all depths on the plots in Oberwarmensteinach compared to Wülfersreuth (Fig. 6). Minimum pH-values do not show any differences between the two stands. Proton concentration in the mineral soil in Oberwarmensteinach and Wülfersreuth is insignificantly lower than in the throughfall, with the exception of the limed plot 5. Comparing pH-values of the percolation water at specific depths, an increase can be seen between the lower litter surface and the first suction cup. Changes in pH with increasing mineral soil depths are insignificantly small in both forest stands. Even on plot 5, the liming effect, which is obvious in the lysimeter pH-values, could not be shown in the suction cups.

These different distributions of proton concentrations on the investigated sites are probably caused by a different soil chemical status in Oberwarmensteinach than in Wülfersreuth (Kaupenjohann 1989) and the significantly higher proton input into the former stand. The podzol in Oberwarmensteinach is exposed to a higher proton input by throughfall and by equivalent release into the rhizosphere of protons buffered in the canopy. Contrary to the data of Reiter et al. (1986), who measured total buffering of protons in the litter layer, only a small part of proton input are buffered in the litter layers of Oberwarmensteinach and Wülfersreuth. This fact is an indication of the acidification and decrease of buffering capacity in the investigated humus layers. In the mineral horizons, pH-values are mainly regulated by the exchange buffer range in Wülfersreuth and the aluminum buffer range in Oberwarmensteinach (Ulrich 1981b).

Matzner (1985) reported a decrease of pH-values after mineral fertilization for two years. This effect cannot be proven on our mineral fertilization plots, perhaps because the acid pulse happened during the 16 months between fertilization and start of our measuring period. On plot 5 the known phenomenon, that lime does not cause any change of pH-values in the mineral soil deeper than 10 centimeters three years after fertilization was measured (Matzner et al. 1983, Matzner 1985, Reiter et al. 1986).

Looking at the weekly pH-values in soil soluations which are mean values of the respective weeks, seasonal changes are quite small at all depths. Minimum values were measured during snowmelt and not during late summer dryness as reported by Matzner and Thoma (1983) or Hauhs (1985). Consequently, no acid pulses caused by increased mineralization could be measured during the observation period.

Calcium and Magnesium

Ca- and Mg-concentrations in throughfall of Oberwarmensteinach and Wülfersreuth (Fig. 7 and 8) are heavily changed by soil chemical processes and the different fertilization treatments. Concentrations of both base cations are lower in the soil solution of the damaged control stand in Oberwarmensteinach than of the healthy control stand in Wülfersreuth. On fertilization plot 2 ($MgSO_4$ x H_2O) a Mg-increase on both sites can be measured in the whole profile, while Ca increases only in Wülfersreuth. The limed plot 5 ($CaCO_3$ x MgO) is characterized by a high increase of Mg in all solution samples on both sites. Calcium, however, shows only a slight increase in the profile of plot 5 in Oberwarmensteinach and an increase in the lower two suction cups in Wülfersreuth.

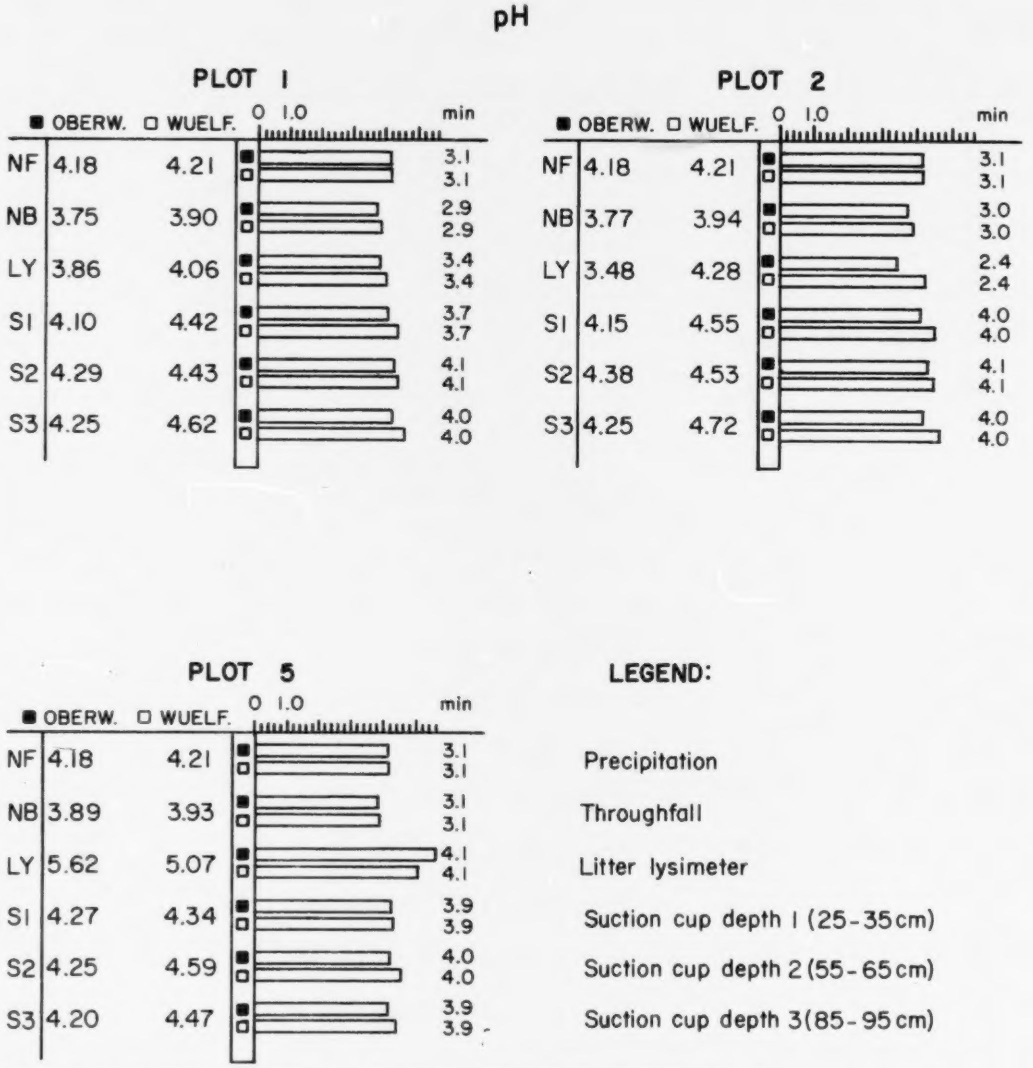

Figure 6.--Mean value of the period July 1984 to June 1986 of pH-values on plot 1, 2, and 5 in Oberwarmensteinach and Wülfersreuth.

The distinction of Mg-values on the two control plots and of Ca-concentrations on all plots between Oberwarmensteinch and Wülfersreuth is mainly caused by the different buffer ranges of those soils. The important influence of mineral fertilization on this soil chemical situation can be seen on plot 2. The addition of Mg displaces other cations from the exchange complex and promotes their leaching (Matzner 1985, Kaupenjohann 1989). The increase of Mg-content down to the lowest suction cup shows that this exchange happened throughout the soil profile, because the solubility of $MgSO_4 \times H_2O$ and the percolation rates are both high. Increase of Mg-concentrations on plot 5 is higher, corresponding to the almost 10-times higher Mg-content of the fertilizer amount used. The low increase of Ca-concentrations on plot 5 is likely an effect of the low solubility of lime (Prenzel 1985) and the high sorption of Ca in humus layers (Matzner et al. 1983).

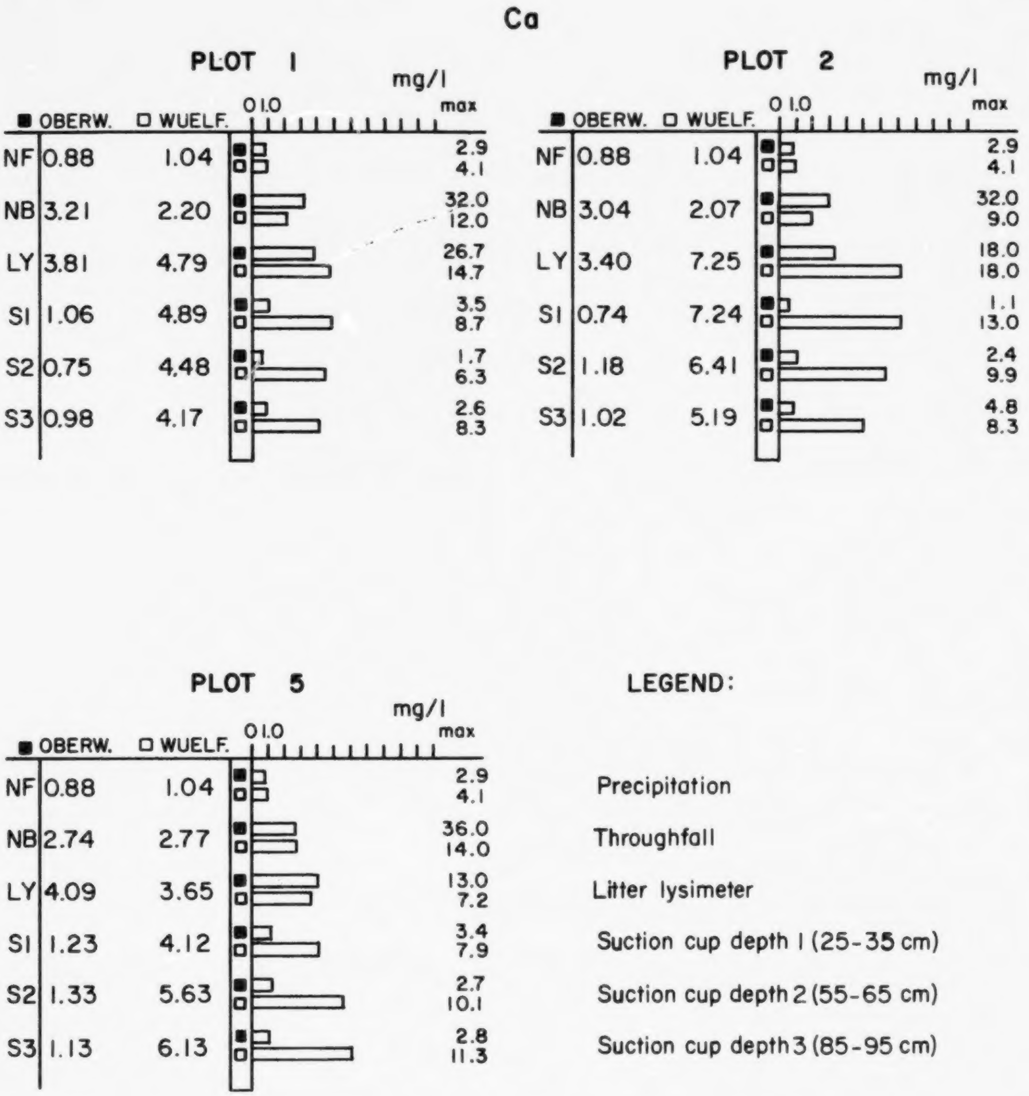

Figure 7.--Mean value of the period July 1984 to June 1986 of Ca-concentrations (mg/l) on plot 1, 2, and 5 in Oberwarmensteinach and Wülfersreuth.

Aluminum

Profiles of Al-concentration are dominated by internal soil process, too (Fig. 9). Input situation is unimportant to the development of Al-concentration in the soils (Hantschel 1987). Solutions in humus lysimeters do not show a significant difference between Oberwarmensteinach and Wülfersreuth. But in the mineral soil the two-year mean values of Al in solution are two to ten times higher in the damaged spruce stand in Oberwarmensteinach than in the healthy one in Wülfersreuth. Mineral fertilization does not change this situation, but on the limed plot, the described differences are reversing or disappearing. The significantly higher Al-concentrations in the profile in Oberwarmensteinach are caused by buffer reactions of the aluminum buffer range. While the amount of fertilized Mg is not enough to displace a lot of Al-ions on the exchange complex of plot 2, this process influences the composition of the soil solution on plot 5. The high leaching of NO_3^- and organic anions accelerates displacement of Al^{3+} as an accompanying cation down to the groundwater level (Dietze 1985, Schierl et al. 1986).

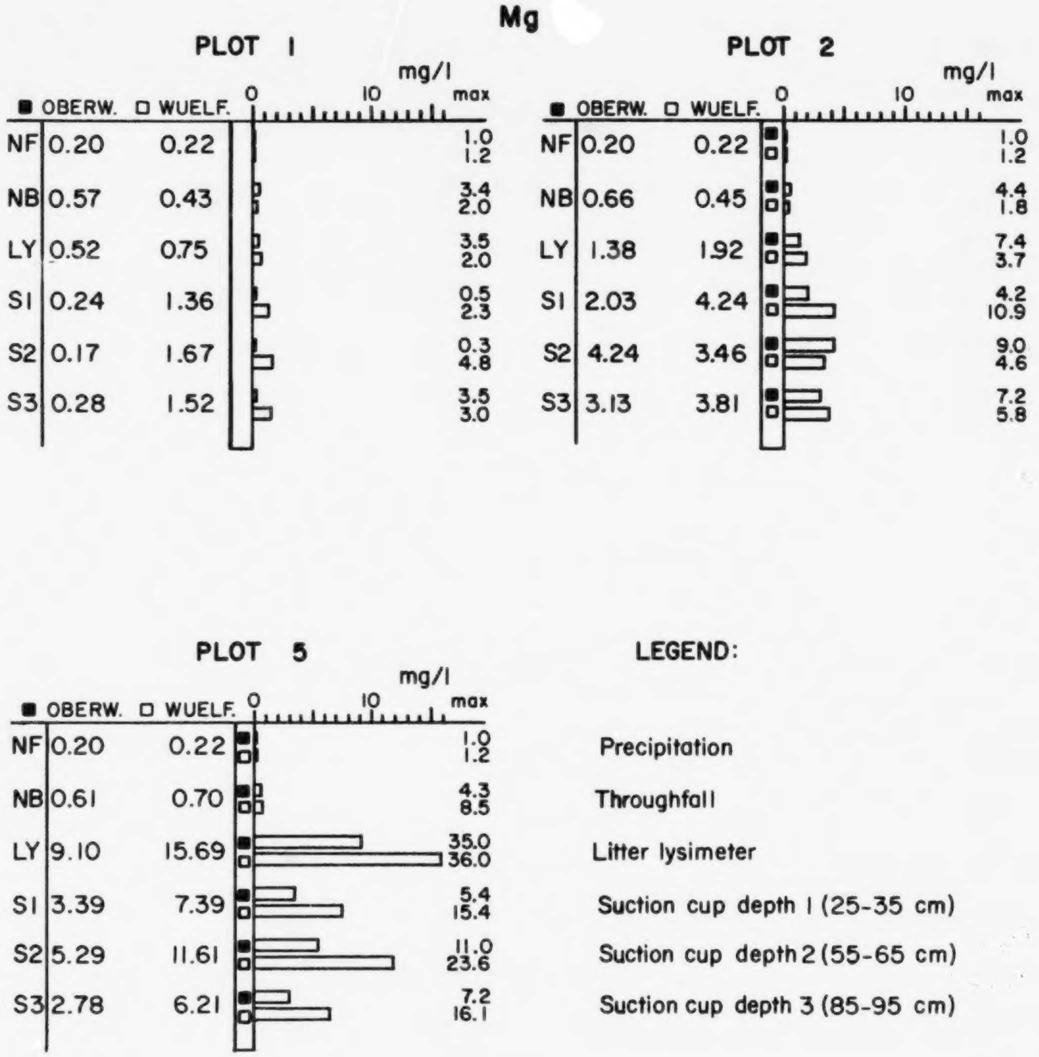

Figure 8.--Mean value of the period July 1984 to June 1986 of Mg-concentrations (mg/l) on plot 1, 2, and 5 in Oberwarmensteinach and Wülfersreuth.

The discussed site differences are summarized in Table 6 which presents the ecologically important Ca/Al- and Mg/Al-ratios in the soil solution. Wülfersreuth is characterized by higher, i.e. ecologically more favorable, element ratios than Oberwarmensteinach. The described fertilization effects are obvious on plot 2 and 5 and emphasize the improved conditions in soil solution on those plots.

Nitrogen

Mean values of NO_3-N concentrations for two years are shown (Fig. 10). NH_4-N values in soil solutions are quite low and are not discussed in this context, but in Element budget in soils Section. No differences can be recognized on the control plots between the single depths on each site and between the two stands. Mineral fertilization (plot 2) causes a distinct decrease of NO_3-N-concentrations in Oberwarmensteinach compared to the control plot, while liming (plot 5) increases NO_3-N values by a factor of two to three on both sites.

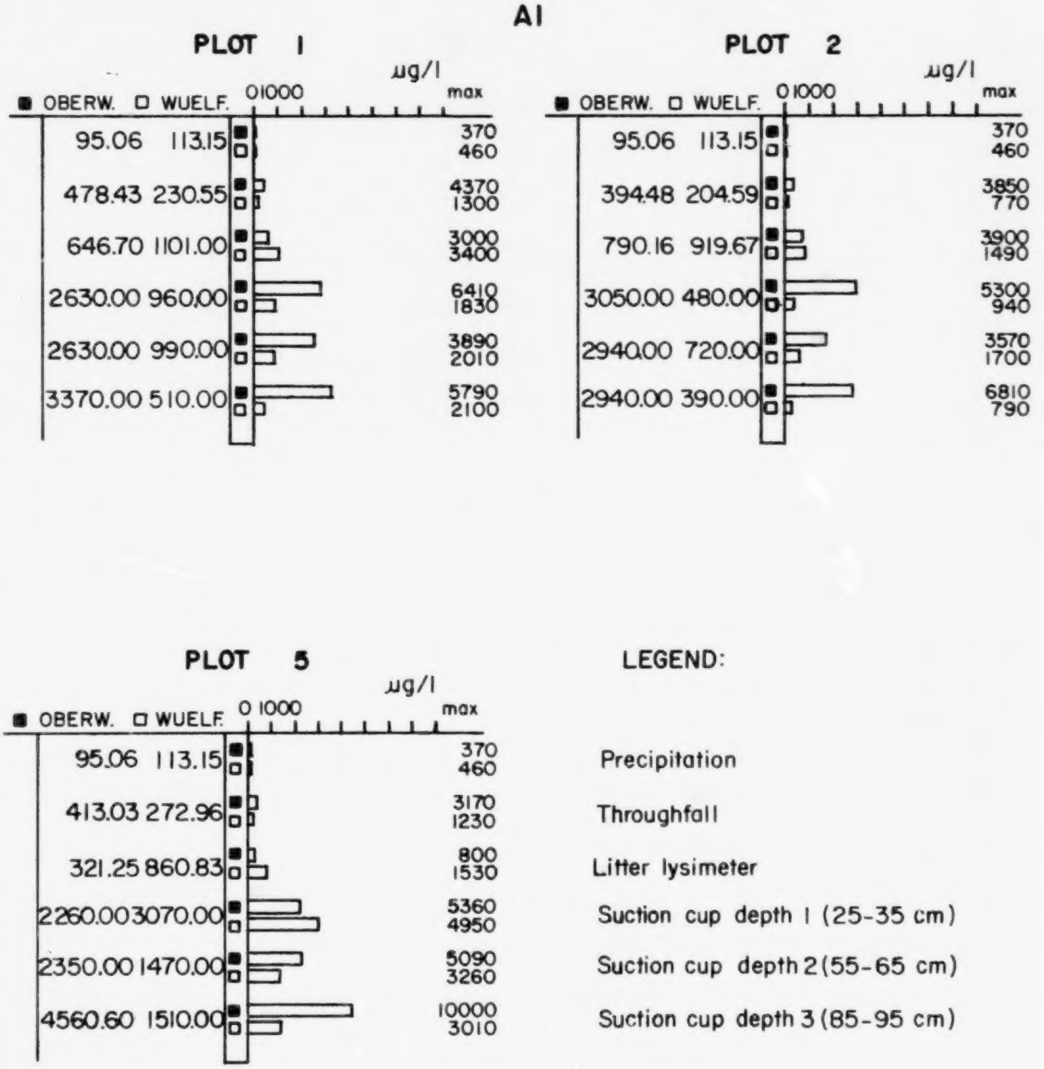

Figure 9.--Mean value of the period July 1984 to June 1986 of Al-concentrations (mg/l) on plot 1, 2, and 5 in Oberwarmensteinach and Wülfersreuth.

On plot 2 in Oberwarmensteinach, uptake of fertilized Mg seems to be accompanied by uptake of NO_3-N which caused the NO_3-N concentration decrease. Nutrient contents of spruces on the plots show a higher Mg-demand and -uptake in Oberwarmensteinach than in Wülfersreuth. The increase in nitrate concentration in solutions of the limed plot 5 has to be considered relatively low in respect to the high amount of fertilized limestone. Similar results are described by Matzner (1985).

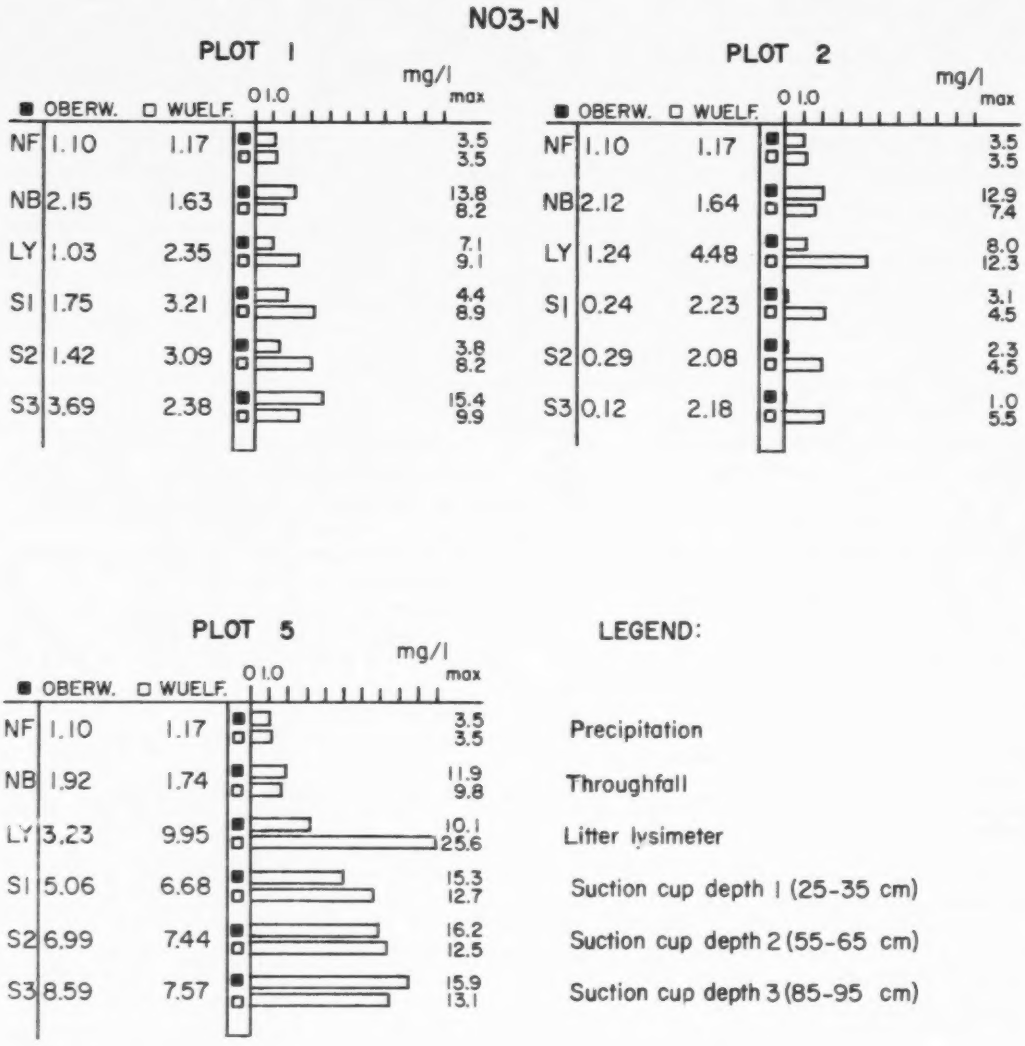

Figure 10.--Mean value of the period July 1984 to June 1986 of NO_3-N-concentrations (mg/l) on plot 1, 2, and 5 in Oberwarmensteinach and Wülfersreuth.

Table 6.--Mole ratios of Ca/A1 and Mg/A1 in litter lysimeter and mineral soil solution (sucking cups S1-S3 in 30, 60, and 90cm depths) of plot 1, 2, and 5 in Oberwarmensteinach (O) and Wülfersreuth (W) (calculated using concentration mean values of the two-year period)

	O								W							
	Ca/Al				Mg/Al				Ca/Al				Mg/Al			
Plot	L	S1	S2	S3	L	S1	S2	S3	L	S1	S2	S3	L	S1	S2	S3
P 1	4.0	0.3	0.2	0.2	0.88	0.10	0.07	0.09	2.9	3.4	3.0	5.5	0.76	1.57	1.87	3.31
P 2	2.9	0.2	0.4	0.2	1.94	0.74	2.62	1.18	5.3	4.9	6.0	4.9	2.32	9.81	5.34	4.33
P 5	8.6	0.4	0.4	0.2	31.60	1.67	2.50	0.68	2.9	0.9	2.6	2.7	20.27	2.67	8.78	4.69

Element budget in soils

An element budget contains the following components (Hauhs 1985):

Percolation output = Deposition Input - Plant Growth Demand +
+ Silicate Weathering Release + Base
Saturation (exchange complex)

The annual fraction of elements circulating with needle and root litter is not considered in this equation. Additionally, it has not been possible to quantify amounts like plant growth demand, release of cations by silicate weathering, and change of base saturation. Therefore, these are not split in the interpretation of the ecosystem budget.

All discussed ions show a logical relation between element fluxes and half-year seepage amount. Especially the relatively dry second half-year of 1985 is characterized by low element fluxes on both investigated sites compared to the rest of the measuring period.

Lower precipitation amounts in Wülfersreuth than in Oberwarmensteinach causes lower seepage amounts in the healthy stand and consequently influences ion fluxes (Hantschel 1987). Besides, it is important to consider the different sampling period in 1984 on the both sites. In Oberwarmensteinach we could obtain soil solutions only for five, in Wülfersreuth only for three months. Therefore, it is not possible to compare element fluxes of this half-year with other half-years or between stands. In Wülfersreuth, fluxes are only listed for depths, which are not influenced by upper top water. In the following presentation of results, a comparison between fluxes in the single half-year periods is not discussed, because seasonal effects can only be proven for long-term measuring periods.

Protons

While in Oberwarmensteinach on plot 1 proton fluxes with mineral soil input (0.12 $g/m^2/1985$;) are not reduced compared to throughfall input, mineral soil in Wülfersreuth (plot 1) receives only half of throughfall flux (0.05 $g/m^2/1985$; Fig. 11). Mineral fertilization in Oberwarmensteinach results in an increase of proton input to the mineral soil in two half-year periods, against that H^+-input decreased during the whole measuring period in Wülfersreuth. Proton fluxes in litter lysimeters on the two limed plots are always significantly reduced. Proton fluxes through the mineral soil do not show important differentiation with depth and over plots on both sites, but fluxes are generally higher in the damaged stand in Oberwarmensteinach than in the healthy one in Wülfersreuth. In the former stand 0.03 g/m^2 leaves the profile in 1985, in the latter one 0.01 g/m^2.

The different H^+-input into the mineral soil on the two investigated sites reflects the distinct deposition situation and percolation amounts as well as the higher proton release in the rhizosphere of Oberwarmensteinach caused by a higher canopy buffering rate than in Wülfersreuth (see Element fluxes in canopies of young spruces Section). The importance of litter layers as a main rooting horizon in spruce stands of the Fichtelgebirge could be shown by Schneider and Zech (1987). The increase of proton fluxes on the mineral fertilization plot 2 was described by Matzner (1985) and Hildebrand (1987). Cations of fertilizers, in this case Mg, are taken up by roots or fixed on humic substances.

The corresponding anions of mineral fertilizers, mostly NO_3^- or SO_4^{2-}, are mobile and remove protons from the charge balance. In Wülfersreuth these protons are buffered again by Ca in the O_H-layer, which is thicker and has a higher buffer capacity than that in Oberwarmensteinach. Therefore, mineral fertilization causes no acid pulse in litter percolates of the healthy spruce stand. The acidic load entering the mineral soil is buffered at least by 50% until reaching the first suction cup in the B-horizon on both sites. Also the acidic pulse on plot 2 is buffered by the mineral soil above the suction cup. In the layers beneath this depth no mentionable changes of proton fluxes have been measured.

Although proton flux with litter outflow is reduced drastically on the limed plot 5 in Oberwarmensteinach and Wülfersreuth, no significant reduction of H^+-transport in the mineral soil can be proven even three years after fertilization. Proton fluxes are dominated by soil chemical conditions in the profiles. Therefore higher H^+-fluxes could be measured in Oberwarmensteinach, characterized by the Al-buffer range, than in Wülfersreuth where the exchange buffer range dominates. Comparing all fertilization plots to the control plot, no significant change of proton output can be proven. Nevertheless, acidity of output water, an important ecological parameter, which consists of the sum of all acidifying cations, i.e., $H^+ + Al^{3+} + Fe^{2+} + Mn^{2+}$ (Matzner et al. 1983) can show different tendencies. This parameter is discussed in Summarizing discussion of ecosystem budget Section.

Potassium, Calcium, and Magnesium

Differences in K-, Ca- and Mg-fluxes through soils on plot 1 between Oberwarmensteinach and Wülfersreuth are presented (Fig. 12 to 14). The damaged stand is characterized by higher K- and lower Ca- and Mg- fluxes with seepage water than the healthy one. Soil solution on fertilization plot 2 reacts with considerable K-reduction, a Mg-increase and no significant Ca-changes. The reaction upon Mg-addition is more intense in Oberwarmensteinach than in Wülfersreuth. Remarkably, the limed plot 5 does not show Ca-increases in soil solutions, with the exception of the subsoil in Wülfersreuth, whereas Mg-fluxes distinctly increase in both stands.

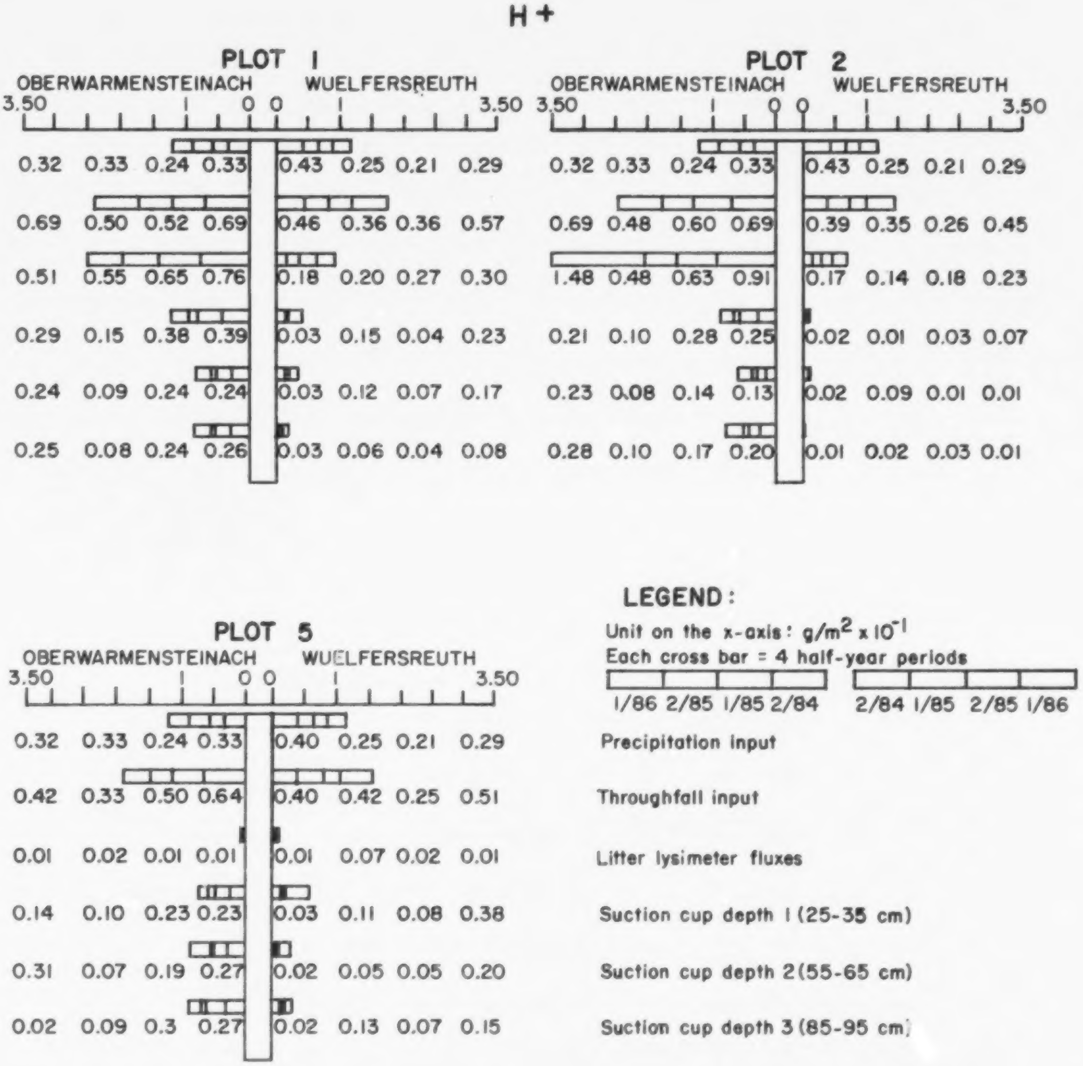

Figure 11.--Proton fluxes (g/m^2 x 10^{-1}) in the different ecosystem compartments in Oberwarmensteinach and Wülfersreuth on plot 1, 2, and 5 from July 1984 to June 1986.

Differences in alkaline earth contents in the mineral soils of both sites are also obvious in total contents of K, Ca, and Mg in the fine earth of single soil horizons (Kaupenjohann 1989). Afterwards, this differentiation is marked best in the C_v-horizons. It is probably caused by a different composition of soil building phyllites and phyllite-schists. Main influences on the Ca- and Mg-composition of the soil solution, however, are exerted by the different buffer mechanisms in Oberwarmensteinach and in Wülfersreuth. In the latter healthy stand protons are buffered mainly by exchange of Ca and Mg against Al-hydroxo-compounds (Nätscher et al. 1987).

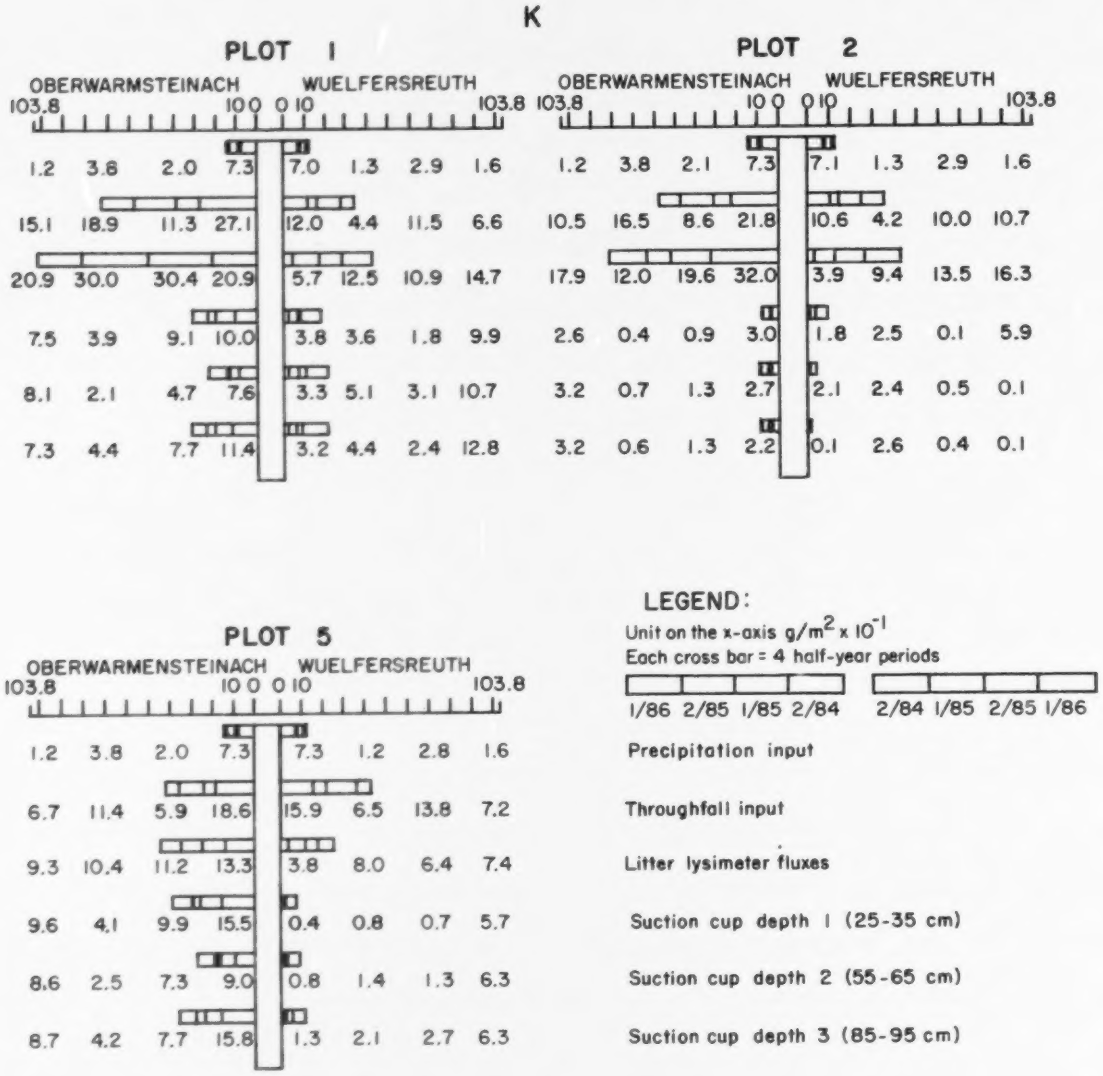

Figure 12.--K-fluxes ($g/m^2 \times 10^{-1}$) in the different ecosystem compartments in Oberwarmensteinach and Wülfersreuth on plot 1, 2, and 5 from July 1984 to June 1986.

Fluxes on fertilization plots are dominated by the ion exchange processes of fertilized ions and the leaching of exchanged ions. These interrelations can be seen best in the decrease of K-fluxes on plot 2. The increase of fertilized ion fluxes with seepage water in all depths of plot 2 and for the whole measuring period proves the fast solubility and displacement of the fertilizer used. Mg-ions of the half-calcined dolomite, used on plot 5, are also leached down to bedrock, while the very slowly soluble calcium carbonate cannot increase Ca-fluxes on this plot. In spite of the fast Mg-displacement, a surprisingly high percentage of added Mg has been sorbed in the mineral soil. On plot 2 two years after fertilization, about 30% of added Mg are stored in the upper 30 cm of mineral soil (= 5.3 g/m^2) and on plot 5 about 29% of fertilized Mg were measured on the exchange complex in this layer (= 85 g/m^2, Horn et al. 1987).

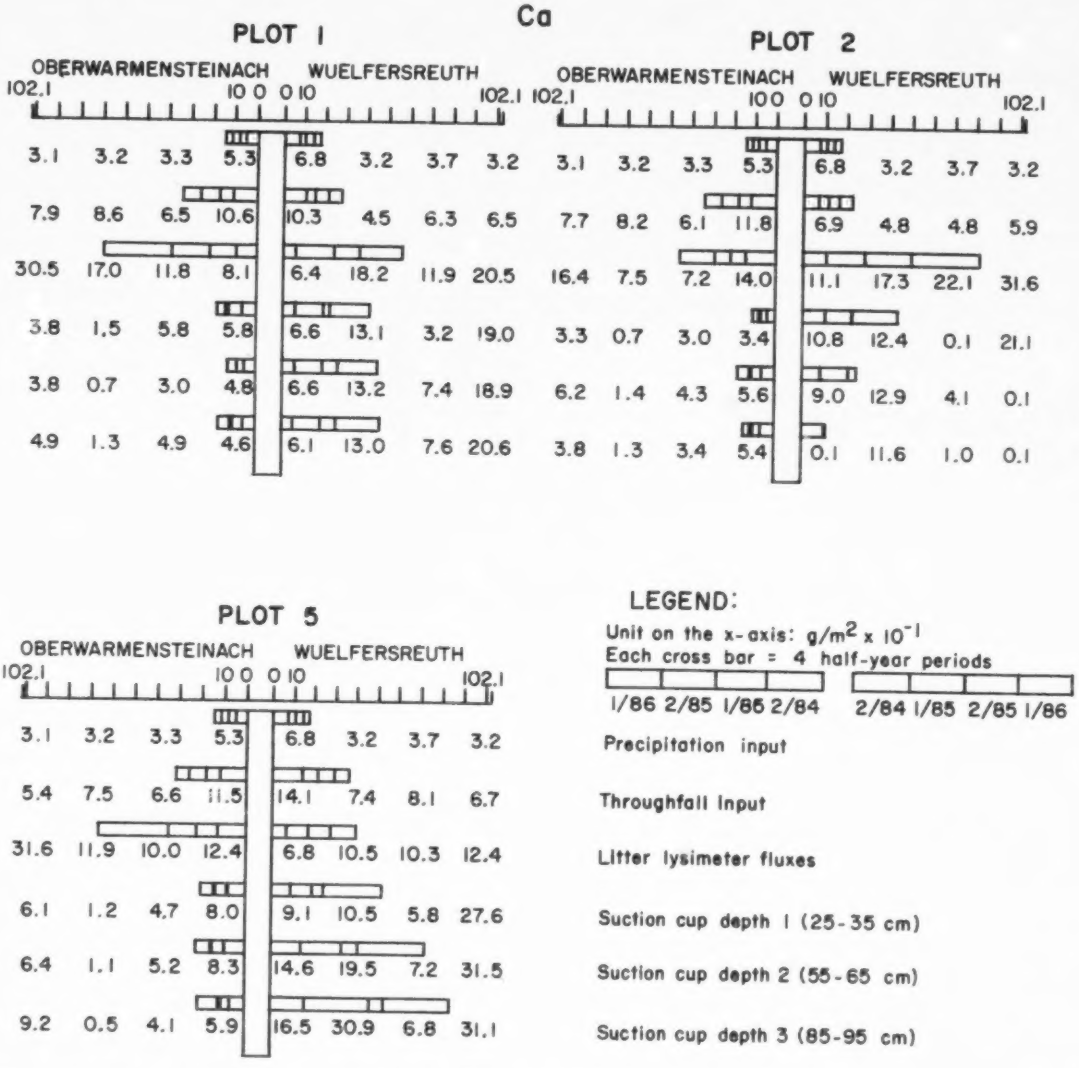

Figure 13.--Ca-fluxes ($g/m^2 \times 10^{-1}$) in the different ecosystem compartments in Oberwarmensteinach and Wülfersreuth on plot 1, 2, and 5 from July 1984 to June 1986.

Aluminum

Aluminum fluxes are quite different on all plots of both sites, even if mineral soil input of A1 is similar (Fig. 15). Generally, A1-fluxes in Oberwarmensteinach are several times higher than in Wülfersreuth. Plot 2 shows increased A1-contents in percolation water on both investigation sites. On the limed plot 5 this tendency is obvious only in Wülfersreuth.

Ecologically important differences in A1-transport between both sites are caused by the buffer mechanisms discussed repeatedly. While in Wülfersreuth proton buffering results in base cation release, in Oberwarmensteinach the protons mainly react with polymeric A1-hydroxo-cations, which are fixed on clay surfaces, and significantly increase $A1^{3+}$-concentrations in seepage water (Ulrich 1981b).

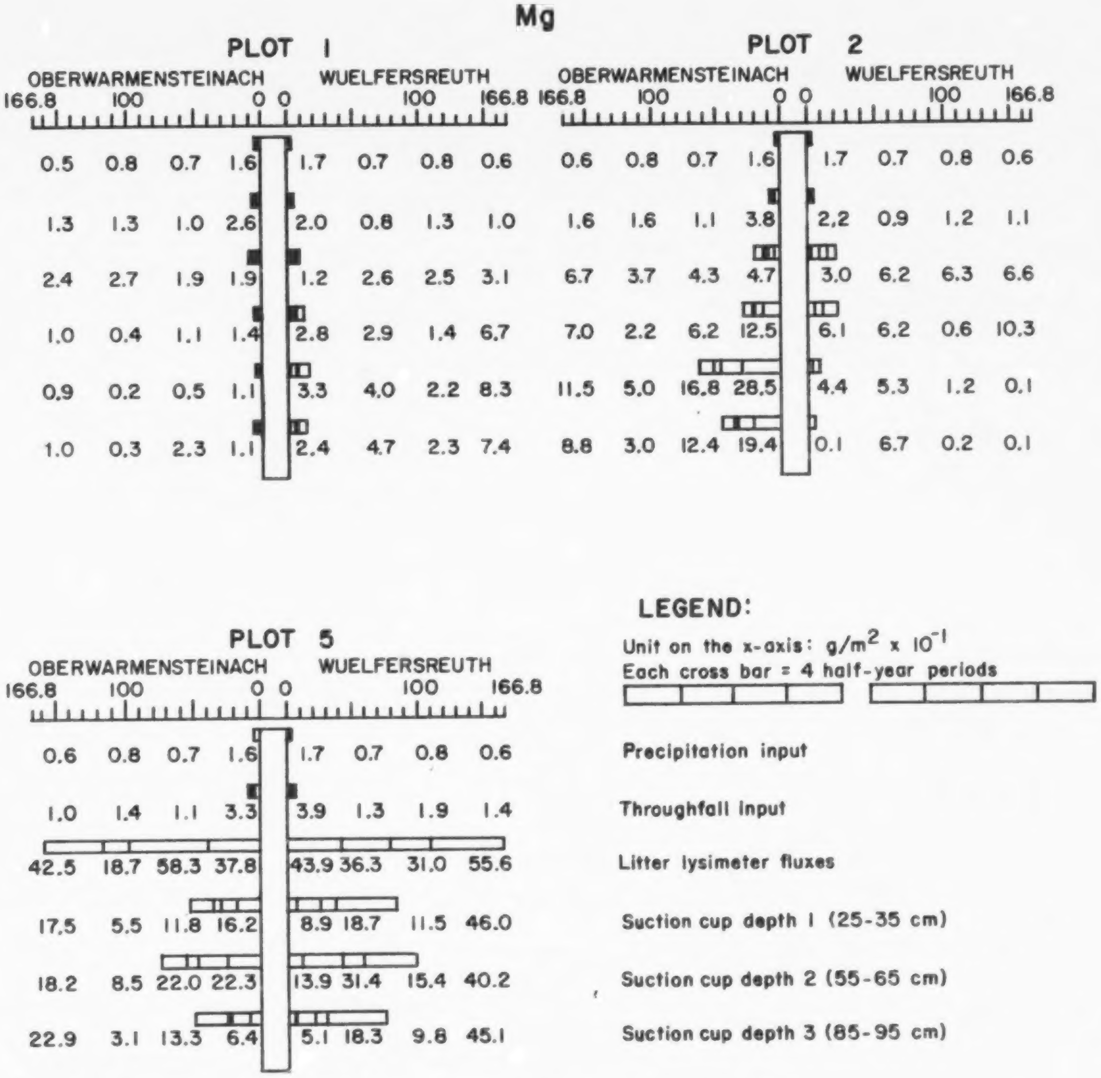

Figure 14.--Mg-fluxes (g/m^2 x 10^{-1}) in the different ecosystem compartments in Oberwarmensteinach and Wülfersreuth on plot 1, 2, and 5 from July 1984 to June 1986.

The known phenomenon of Al-removal from the exchange complex by fertilized ions (Matzner et al. 1983) can be measured only on plots 3 and 4 in Oberwarmensteinach which are not shown. Two and three mineral fertilizers were used there, respectively (Hantschel 1987). One cause for the lack of this phenomenon on plot 2 and 5 in the damaged stand could be a different soil chemical status of these single plots. Aluminum does not change on fertilization plots in Wülfersreuth because exchange processes mainly affect other sorbed ions.

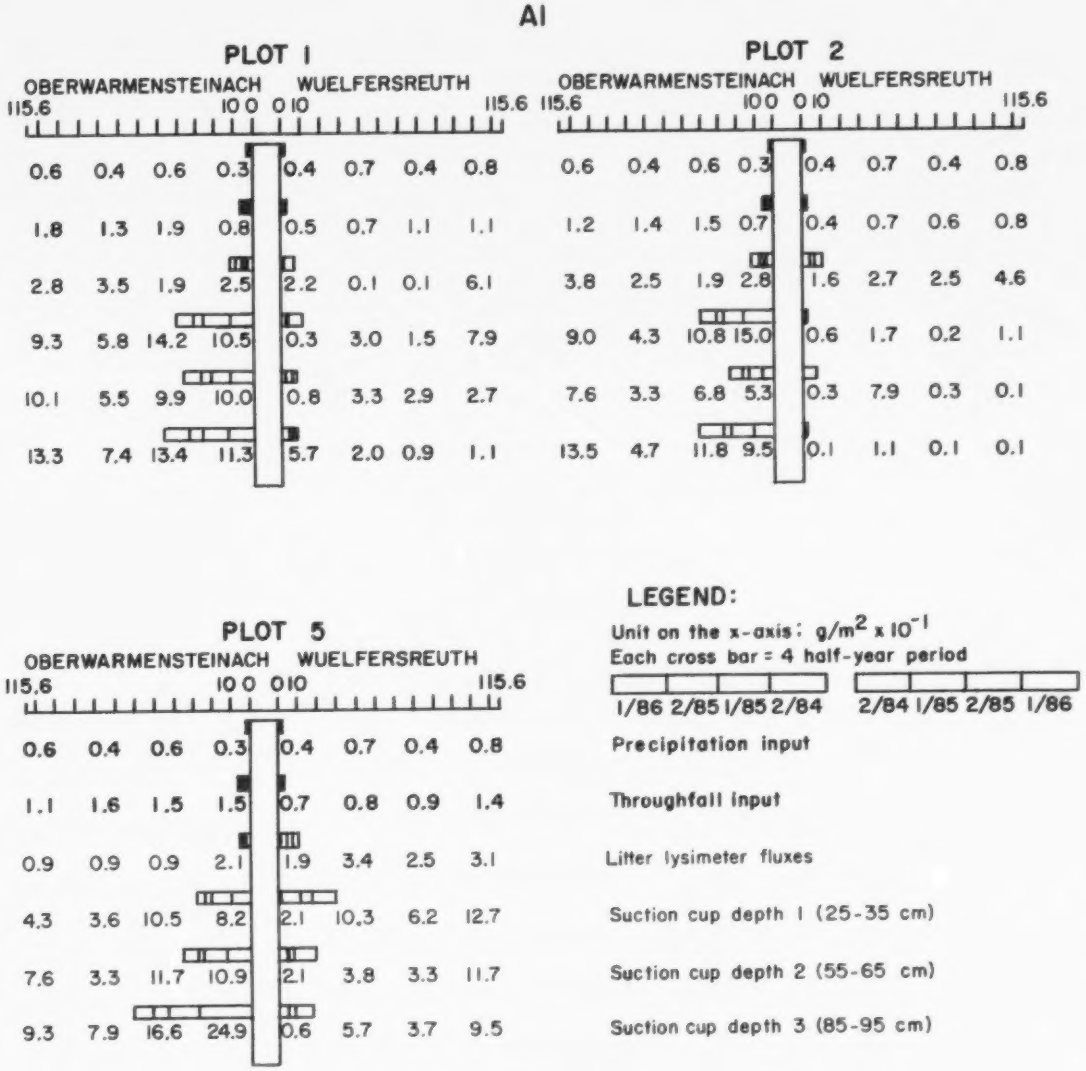

Figure 15.--Al-fluxes (mg/m^2 x 10^{-1}) in the different ecosystem compartments in Oberwarmensteinach and Wülfersreuth on plot 1, 2, and 5 from July 1984 to June 1986.

Nitrogen

NH_4-fluxes reach their maxima in mineral soil input on all plots in Oberwarmensteinach and Wülfersreuth, with the exception of plot 5 (Fig. 16, 2.5 $g/m^2/1985$ on plot 1 in Oberwarmensteinach and 3.9 $g/m^2/1985$ on plot 1 in Wülfersreuth). Only very small amounts of NH_4-N are displaced through the mineral soil profile on both sites and independent of treatment (maximum output 0.07 $g/m^2/1985$ on plot 3 in Oberwarmensteinach (Hantschel 1987) and 0.01 $g/m^2/1985$ on plot 1 in Wülfersreuth). NO_3-N shows low variations of fluxes with increasing soil depth on both control plots (Fig. 17; output 2.3 $g/m^2/1985$ on plot 1 in Oberwarmensteinach and 1.5 $g/m^2/1985$ in Wülfersreuth). On plot 2 however, a reduction of NO_3-fluxes through the mineral soil can be seen on both sites. Liming treatment (plot 5) causes a significant increase of NO_3-N in percolation fluxes in Oberwarmensteinach (output 4.4 $g/m^2/1985$) and Wülfersreuth (output 4.6 $g/m^2/1985$).

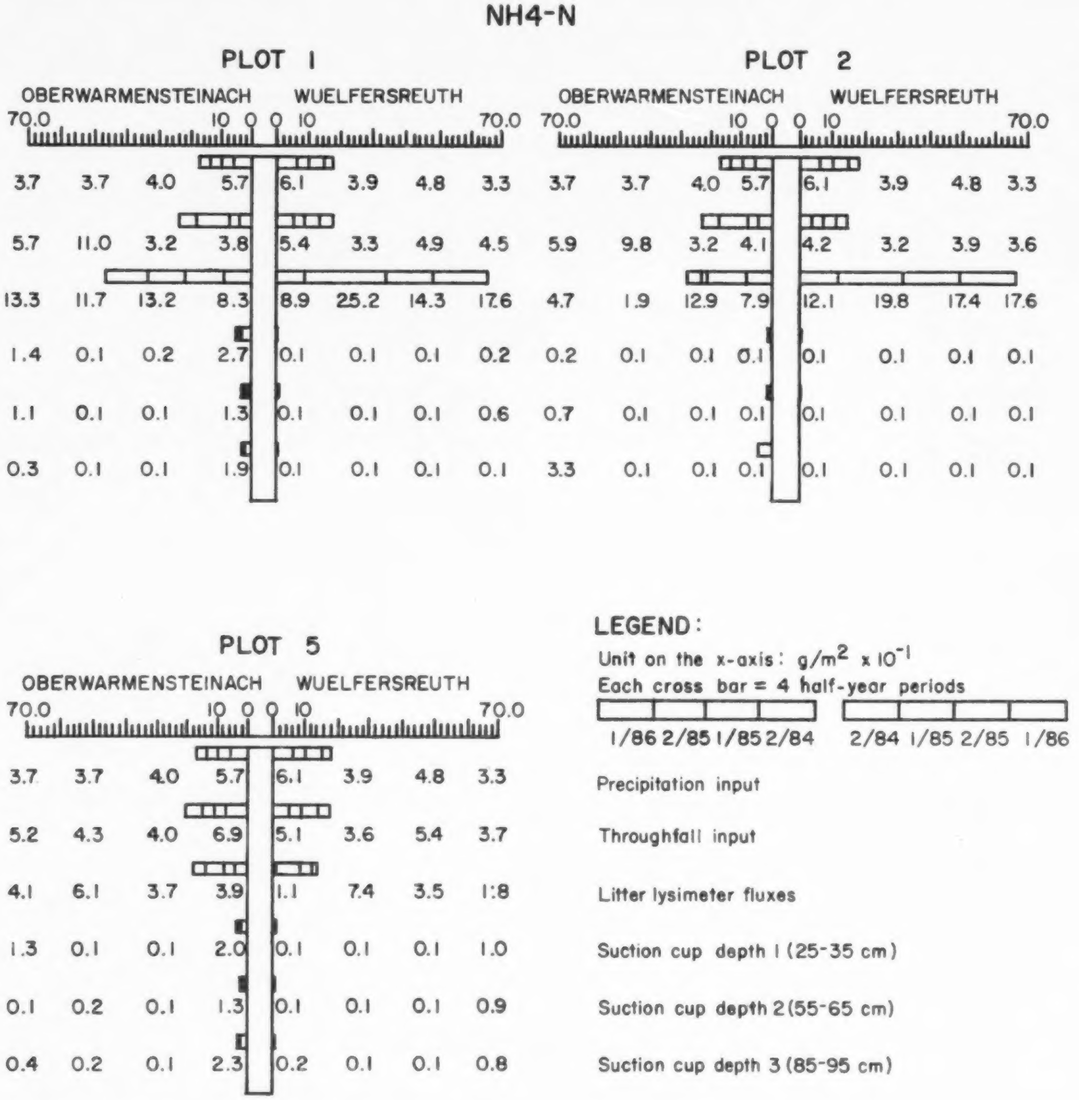

Figure 16.--NH_4-N-fluxes ($g/m^2 \times 10^{-1}$) in the different ecosystem compartments in Oberwarmensteinach and Wülfersreuth on plot 1, 2, and 5 from July 1984 to June 1986.

NH_4-N/NO_3-N-ratios in mineral soil input are not discussed further because there might be some analytical problems using weekly samples caused by microbiological transformation processes. Total nitrogen fluxes with mineral soil input on control plots exceed the throughfall input by 10% in Oberwarmensteinach and lie about 40% lower in Wülfersreuth. The very low values of NH_4-fluxes in the mineral horizons are probably based on NH_4-N nutrition of spruces and NH_4-N fixation on three-layer clay minerals (Beese and Matzner 1986, Kaupenjohann 1988). NH_4-N nutrition of spruces results in reduced uptake of K, Ca, and Mg by roots and in acidification of the rhizosphere (Van Breemen et al. 1984). These processes deteriorate plant nutrition and acid neutralization capacity of trees as well as chemical conditions in the area of nutrient uptake. Accordingly, no significant NO_3-N-reduction in soil solution was caused by plant uptake in Oberwarmensteinach and Wülfersreuth. Uptake of NO_3-N is indicated on plot 2. It can be declared by an increased plant activity and uptake after fertilization of the deficient nutrient Mg. Spruces cannot use the greatly increased NO_3-N-offer on the limed plots 5, which is a result of the raised litter mineralization. But trees show higher cation uptake after liming and therefore reach higher alkalinity (Beese 1986).

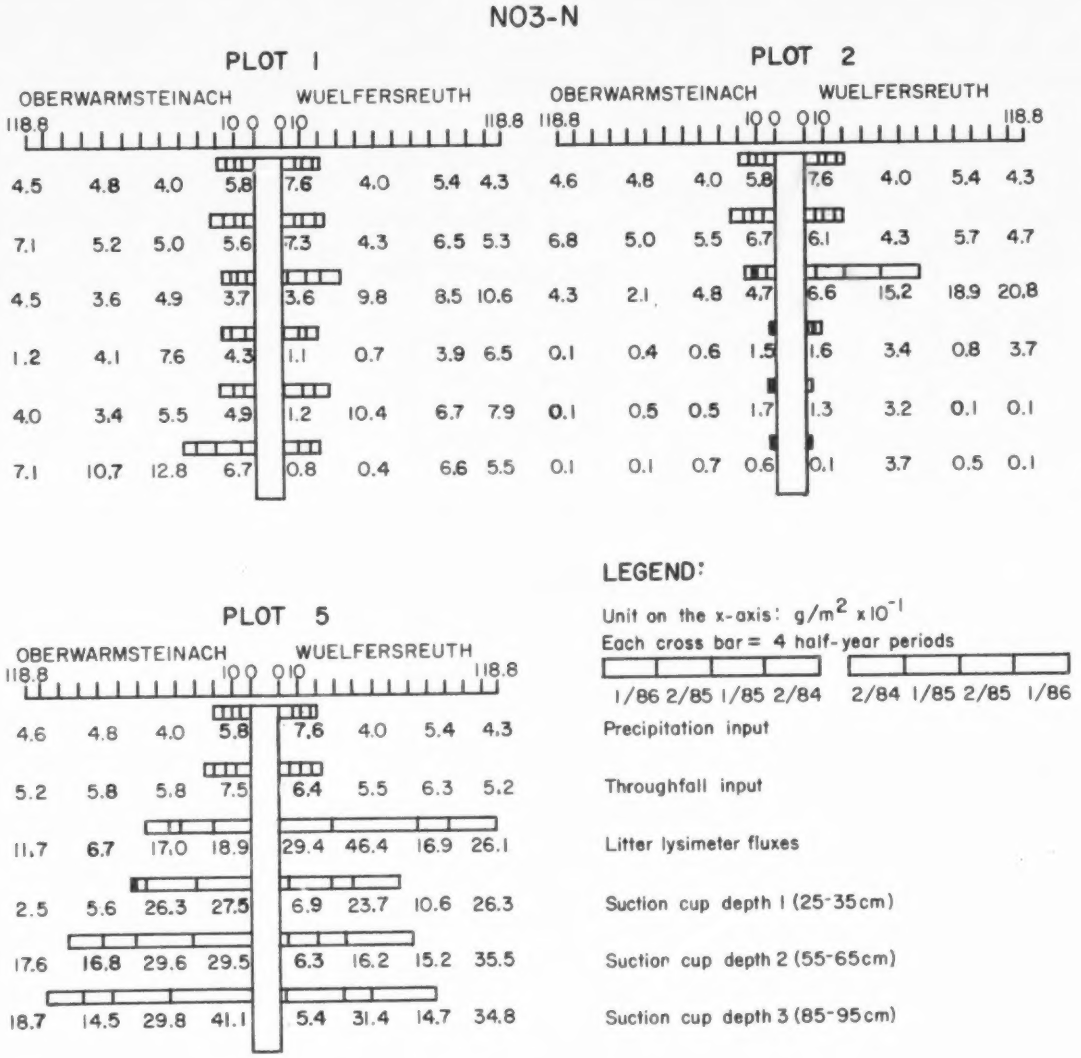

Figure 17.--NO_3 -N-fluxes (g/m² x 10^{-1}) in the different ecosystem compartments in Oberwarmensteinach and Wülfersreuth on plot 1, 2, and 5 from July 1984 to June 1986.

Sulfate

Oberwarmensteinach is characterized by higher SO$_4$-S fluxes in all soil depths than in Wülfersreuth (Fig. 18; output 2.7 g/m^2/1985 on plot 1 in Oberwarmensteinach and 1.7 g/m^2/1985 on plot 1 in Wülfersreuth). Generally, mineral soil input represents the highest flux. Plot 2 reflects the usage of a fertilizer containing the SO$_4$-anion. Liming (plot 5) increases the transported SO$_4$-S amounts only in the mineral soil of Wülfersreuth.

The higher SO$_4$-fluxes in Oberwarmensteinach are probably caused by a significantly higher sulfur deposition than in Wülfersreuth. Humus layers can store large amounts of sulfur (Zucker et al. 1986), but also release them as documented by the high mineral soil input. Total sulfur fluxes released by litter decomposition contribute less than 10% of throughfall deposition to the total input (Hantschel 1987), however, sulfur content of needles if quite high on these stands (Kaupenjohann et al. 1987). Farrell et al. (1984) describe sesquioxides as the main sorbing substances in the mineral soil. Afterwards, this sorption capacity can be exceeded by high SO$_4$-S-deposition (Zucker et al. 1986). It is questionable whether sesquioxides control SO$_4$-concentrations in the investigated soils. Another storage mechanism for SO$_4$ is

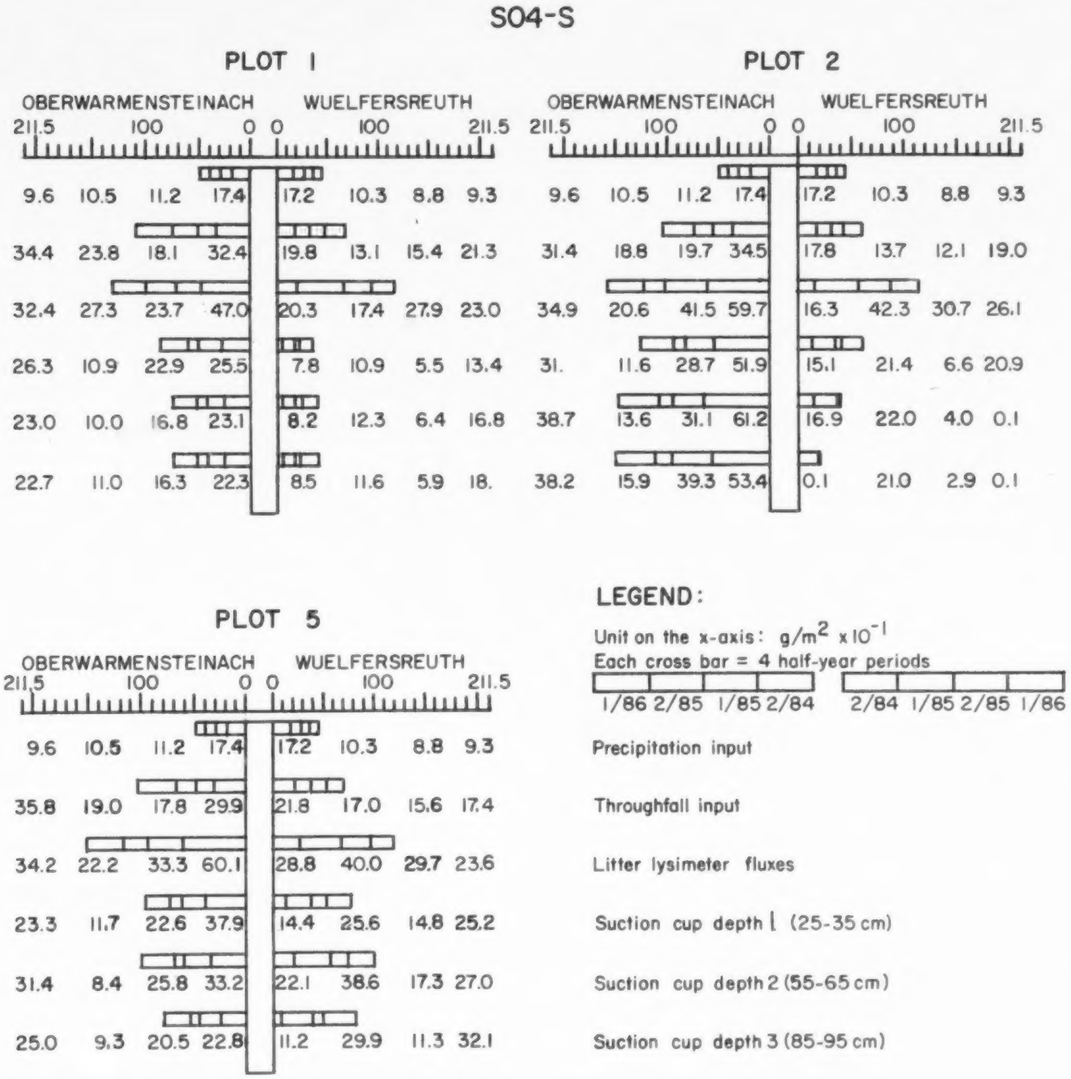

Figure 18.--SO$_4$ -S-fluxes (g/m^2 x 10^{-1}) in the different ecosystem compartments in Oberwarmensteinach and Wülfersreuth on plot 1, 2, and 5 from July 1984 to June 1986.

described by Prenzel (1982). Over a small pH-range between pH 4 and 5 sulfur and aluminum can be stored as aluminum hydroxosulfates, similar to the mineral jurbanite ($AlOHSO_4$). If soils are acidifying below the equilibrium pH-value, Al and SO_4 are released again (Prenzel 1983). Storage of SO_4-S in the mineral soil, especially in Wülfersreuth, is an indication of the existence of $AlOHSO_4$-compounds (Khanna et al. 1987). Calculations using chemical composition data of the percolation soil solution (Hantschel et al. 1988) also delivers arguments for the existence of $AlOHSO_4$ (Kaupenjohann et al. 1989). $MgSO_4$-fertilization presents the expected increase of SO_4-S-fluxes on both sites. While in Oberwarmensteinach no significant change can be measured with increasing depth, in Wülfersreuth fluxes decrease from litter outflow to soil output indicating a higher sorption or precipitation of SO_4 in this profile. Plot 5 shows a sharp increase of SO_4-S-fluxes in mineral soil only in Wülfersreuth. Possibly sulfate serves as accompanying anion for the higher cation output in Wülfersreuth than in Oberwarmensteinach.

Heavy Metals

No ecologically important change of Zn-, Cd-, Cu-, and Pb-fluxes on the fertilization plots could be proven. Only the two control plots will be discussed (Fig. 19). Existing differences between Oberwarmensteinach and Wülfersreuth reflect different total content of heavy metals in fine earth fractions (Table 7). The podzol in Oberwarmensteinach is characterized by higher Cd-values over the whole profile and higher Pb-contents in the humus layer, while Zn shows higher in all horizons of the podzolic cambisol in Wülfersreuth. Cu-contents do not differ significantly between the sites. These differences in total contents are well reflected in the two-years mean values of Zn, Cd, Pb, and Cu (Hantschel 1987), but they are obscured in the heavy metal fluxes, e.g. for Zn, because of the higher seepage amount in Oberwarmensteinach than in Wülfersreuth equalizes differences. Additionally, the connection between contents in fine earth and concentration in solution is influenced by the pH-dependency of heavy metal solubility (Herms and Brümmer 1984). The lower pH-values in Oberwarmensteinach than in Wülfersreuth cause higher solubility of all discussed heavy metals.

Nevertheless, Zn-fluxes in Wülfersreuth are slightly higher than in Oberwarmensteinach (output 58.5 $mg/cm^2/1985$ in Oberwarmensteinach and about 100 $mg/m^2/1985$ in Wülfersreuth) with the exception of mineral soil input, as well as Cu-fluxes (output 5.7 $mg/m^2/1985$ in Oberwarmensteinach and about 15 $mg/m^2/1985$ in Wülfersreuth). Cadmium fluxes in Oberwarmensteinach are higher than in Wülfersreuth (output 1.9 $mg/m^2/1985$ in Oberwarmensteinach and 1.5 $mg/m^2/1985$ in Wülfersreuth), whereby it is important to know that the limit concentration of drinking water law (6 $\mu g/l$) was exceeded several times during the measuring period (Hantschel et al. 1985). From the litter output to the second suction cup, Oberwarmensteinach shows higher Pb-fluxes than the comparable site, but output levels of Pb are quite similar on both sites (2.5 $mg/m^2/1985$ in Oberwarmensteinach and 2.8 $mg/m^2/1985$ in Wülfersreuth.

While the behavior of Zn and Cd in the investigated profiles is probably dominated by pH-distribution, Pb and Cu-fluxes are mainly determined by their high preference for building organic complexes. Lead is favorably fixed to high molecular weight organic substances which are strongly adsorbed on surfaces (König et al. 1986). Therefore, this heavy metal shows sharply reduced fluxes through mineral soil after high sorption in the humus layer (Tyler 1978, Asche and Beese 1986). Lead humus complexes could be displaced to lower soil horizons by acidic pulses, whereby the complexes are sorbed again on mineral surfaces. Therefore, no high Pb-output is to be expected. Copper, however, is mainly fixed to low molecular weight organic substances, which are weakly fixed. Consequently, higher fluxes of Cu through mineral soils are measurable.

The described reduction of heavy metal fluxes after liming (Lamersdorf 1985) could not be proven on the investigated plots up to now.

Table 7.--Total contents of heavy metals (ppm) in the single horizons of the soil profiles in Oberwarmensteinach (O) and Wülfersreuth (W).

Soil	O					W[+]			
profile	Zn	Cd	Pb	Cu		Zn	Cd	Pb	Cu
L	31	0.29	39	6	L	48	0.33	66	11
Of	69	0.67	147	17	Of	82	0.57	178	18
Oh	65	0.57	220	19	Oh	85	0.93	181	17
Aeh	32	0.33	49	6	Aeh	45	0.13	51	11
Bs	40	0.28	35	7	Bv	57	0.06	34	14
BvCv1	52	0.41	34	10	BvCv1	73	0.06	27	17
BvCv2	-	-	-	-	BvCv2	91	0.05	28	21
Cv	41	0.29	28	9	Cv	93	0.06	29	25

[+] RUPPERT (1986)

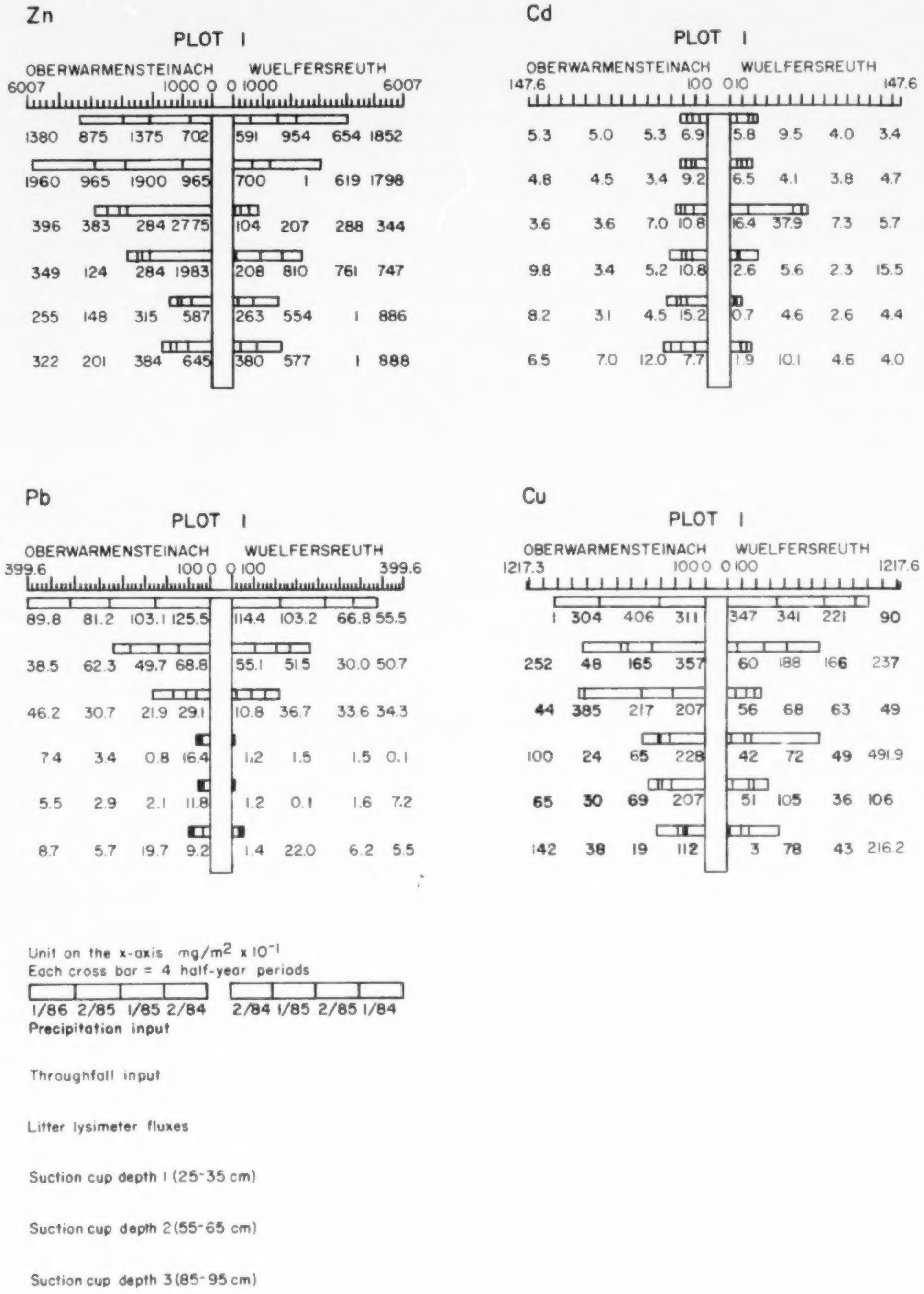

Figure 19.--Heavy metal fluxes (mg/m² x 10⁻¹) in the different ecosystem compartments in Oberwarmensteinach and Wülfersreuth on the control plot from July 1984 to June 1986.

Summarizing discussion of ecosystem budget

Evaluation of the most important element fluxes on control plots in the two investigated spruce stands can be followed in Fig. 20. The listed columns represent data only from 1985. Afterwards it is necessary to measure several years to judge a forest ecosystem (Matzner and Ulrich 1981) this budget is only a first indication of the status of these stands, but allows no certain statement of development from the past up to now or into the future.

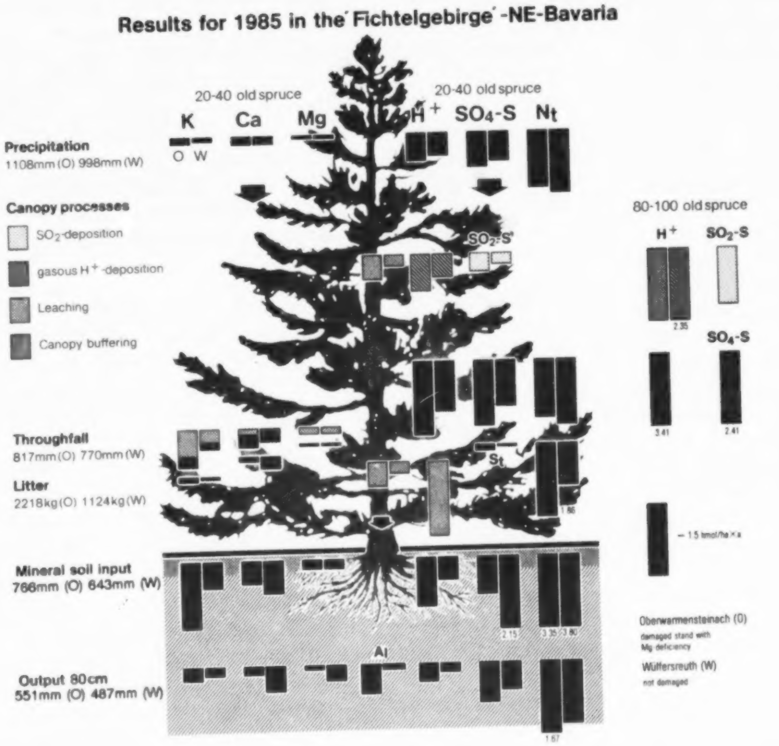

Figure 20.--Ecosystem budget of two young spruce stands (20 to 40 years old) in Oberwarmensteinach and Wülfersreuth and canopy budget of an old spruce stand (100 years old) in Oberwarmensteinach for the investigation period 1985.

Precipitation deposition of acidifying agents, like sulfur and nitrogen, do not significantly differ between Oberwarmensteinach and Wülfersreuth, although precipitation amount is about 11% higher in the former stand (Hantschel 1987). Different dry and gaseous sulfur deposition into the investigated 20- to 40-year-old spruces causes a significant differentiation of the input situation into the damaged stand in Oberwarmensteinach and the healthy stand in Wülfersreuth. Applying a canopy budget model (Ulrich 1983), which neglects nitrogen, we calculated significantly higher SO_2-deposition into the damaged stand. Gaseous input shows the same magnitude as precipitation deposition and, therefore represents an ecologically important input parameter. This SO_2-input results after solution in the water phase in an equivalent proton input, which is significantly higher in Oberwarmensteinach than in Wülfersreuth. In the canopy, protons were buffered by several processes (Cronan and Reiners 1983), dominated by proton exchange against base cations (Mengel et al. 1987) and leaching of weak organic acids (Hantschel and Klemm 1987). Because of these buffering processes, proton input calculations using pH-values of throughfall measurements distinctly underestimate real proton input. The higher pollution of the spruces in Oberwarmensteinach causes significantly higher K-leaching than in the healthy stand. Consequently, the damaged stand is characterized by higher canopy buffering causing higher proton release into the rhizosphere of the podzol than into the podzolic cambisol in Wülfersreuth.

Comparing deposition measurements in an 80- to 100-year-old spruce stand in Oberwarmensteinach illustrates the importance of the filter capacity of trees to element deposition. Thus, SO_2 filtering and H^+-input into old spruces is significantly higher than into young spruces. Therefore, proton input on the same site and on the same substratum, but under old and young trees, respectively, can be quite different, and different soil chemical reactions have to be expected (Hantschel et al. 1988, Kaupenjohann et al. 1989).

Proton fluxes reach a litter layer, which can buffer fewer protons in Oberwarmensteinach than in Wülfersreuth. Element contents in mineral soil input present only an indication of the representative situation, because root uptake and water fluxes are influenced by the installation technique (Hantschel 1987). Ion composition of mineral soil fluxes are dominated by the different proton input of both stands and the different soil chemical buffer ranges. While in Wülfersreuth, most protons are buffered by base cation exchange, mainly Ca, against Al-hydroxo-compounds, in Oberwarmensteinach this buffering is principally done by Al-hydroxo-compounds resulting in increasing Al^{3+}-concentrations. Therefore, output of cations is mainly composed of Ca and Mg in Wülfersreuth and of Al in Oberwarmensteinach. The most important accompanying anions are SO_4^{2-} and NO_3^- in both stands, which underlines the soil acidifying processes in both profiles (Reuss and Johnson 1986). Corresponding to higher cation charge of output in Wülfersreuth, output fluxes of sulfate and nitrate are also higher than in Oberwarmensteinach.

The ecosystem budget, i.e. precipitation input minus seepage output, is negative for K, Ca, and Mg. This fact is markedly more distinct in Wülfersreuth than in Oberwarmensteinach. Base cation supply is higher in the healthy stand with lower podzolisation and those base cations are used for proton buffering. Soils in Wülfersreuth are on the way to reach the status of soils in Oberwarmensteinach if present conditions continue. Then we have to expect decline phenomena in Wülfersreuth, too. Similar developments of forest ecosystems are described by Ulrich (1986a). The much more negative Al-balance - input of Al is unimportant (Hantschel 1987) - in Oberwarmensteinach proves the Al-buffer range and illustrates the pollution of groundwater with toxic Al^{3+}-ions. Besides, groundwater is polluted with higher H^+-fluxes on the damaged stand. Altogether, proton balance is positive on both sites, meaning an increase of base neutralization capacity in the solum. But about 50% of deposited protons leave the profile in Oberwarmensteinach and about 25% in Wülfersreuth. In summary, acidity output with seepage water is significantly higher on the damaged site than on the healthy one.

Sulfate input and output are nearly balanced. At the moment, on both sites, it is not clear whether the profiles will develop toward a sulfate source or sink in the future. Nitrogen balance is slightly negative and explains that decomposition rates of humus layers are higher than the N-uptake and that the spruces cannot use the abundant N-offer. The high N-output, mainly as NO_3-N, causes additional acidification in Wülfersreuth by leaching an equivalent amount of base cations and additional pollution of groundwater in Oberwarmensteinach by taking along Al^{3+}-ions (Reuss and Johnson 1986). Negative influences of high N-input and soil fluxes on spruce nutrition are discussed by Schulze et al. (1987).

The heavy metal balances not shown prove results gained in other studies (Mayer 1981), with the exception of Zn. Lead and copper are characterized by a more or less positive balance because they are intensively sorbed on humic substances. Cadmium shows balanced fluxes in Wülfersreuth and a little higher output in Oberwarmensteinach, probably caused by higher solubility according to lower pH-values. Zinc presents a positive balance on both sites during the measuring period, which do not correspond with data of Mayer (1981) and with poor Zn-supply of spruce on the investigation sites (Kaupenjohann 1989).

Main fertilization effects on the ecosystem budget are initially increased Mg-leaching after Mg-fertilization. This fact indicates that needles of spruce possess damaged needle surfaces in spite of improved nutrient supply. Secondly, mineral fertilization of Mg rapidly increases concentrations of this ion in soil solution and displaces other cations on the exchange complex. Liming with halfcalcined dolomite causes no penetration of buffer front down to the first suction cup in about 30 cm depth until three years after fertilization, but high input of Mg to the whole mineral soil. Therefore acidity output with percolation water cannot be reduced up to now, although most ions of throughfall input are buffered in the humus layers. Lastly, NO_3-increase on the limed plot does not seem to be dramatic, in spite of the high amount of fertilizer.

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Changes In Forest Soils And Tree Vitality As A Consequence of Acid Deposition

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Abstract

According to the Falck-Manion hypothesis, the predisposing factor for forest decline is the continuing deposition of acid to forest ecosystems. This results in depletion of soil nutrients and release of toxic ions into the soil solution. This in turn results in retreat of fine roots into the upper soil horizons and decreased effectivity of the roots for nutrient uptake. The restriction of roots to the supper soil layers increases the susceptibility of the trees to both winter and summer drought.

The Problem

The problem can be defined as follows: The forest ecosystem receives input of material (acidity, nutrients, toxic substances) which causes a change in the state of the components of the ecosystem: soil, trees, ground vegetation, soil organisms. The change in the system changes the characteristics of the material output from the system which occurs almost exclusively with seepage water, in gaseous form and with biomass. To judge whether acid deposition has an effect on forest ecosystem or not, data are necessary describing the initial state of the ecosystem at the beginning of industrialization, the amount of substances deposited since then, the acid/base reactions in the soil, the effect of acid stress on organisms, and the present state of the ecosystem. Without this information it is scientifically impossible to deny an adverse effect of acid deposition. In the following, only a very condensed report on the status of our investigations can be given.

Initial State of Forest Ecosystems

In respect to the chemical state of forest soils, theory and data going back to the 1920's allow the following conclusions:

- Before industrialization, acidification of podzol soils which developed in the post-glacial period was restricted to the top soil (A horizon). The subsoil below, the Bh horizon in 20-30 cm depth, had intermediate base saturation. (cf. Ulrich 1986a)
- In the 1920's the pH values of B horizons of forest soils in areas not especially exposed to deposition (especially exposed are forests down wind of emission sources, and forests intercepting cloud droplets) were predominantly above 5.0. (Ulrich 1987a)
- Still, in the 1950's, the distribution of base saturation in the forest types described by Hartmann and Jahn (1967) had its maximum between values in the range 20-30% (montane beech forests and high montane coniferous forests on acid soils) and above 80% (submontane mixed oak forests, montane beech and mixed beech forests with at least an intermediate nutrient supply. (Ulrich 1987b).

The symptom of needle loss has been documented for some time but only from old trees, from isolated trees, and from forest edges. The symptom of "yellowing with Mg deficiency" has been reported earlier only for the first years of plantations.

Present and Accumulated Deposition

The present rate of deposition of strong acids into forest ecosystems varies in the northern part of Germany between 1, 2, and >6 Kmol acid equivalents ($H^+ + NH_4^+$) per ha and year (cf. Ulrich 1985), depending upon tree species, stand age, and exposure. The deposition rates of N and Ca exceed by far the amount of nutrients necessary for the growth of forest. The deposition of Mg, which originates mainly from sea spray, shows a gradient from northern to southern Germany. It exceeds the Mg requirement only in northern Germany, but not in the South.

In the Solling mountains, the rate of acid deposition has been measured since 1969. For the rate of emission of acid precursors (SO_2, NO_x), data are available for the area of the FRG back to 1850. With the aid of the ratio between emission and deposition rates for the period 1969 to 1985, the deposition rates have been calculated on the basis of the emission data back to 1850 (Ulrich 1987 a). If the annual rates of acid deposition thus calculated are summed, the accumulated acid deposition amounts to 200 Kmol H^+/ha in the spruce forest, and 100 Kmol H^+/ha in the beech forest. According to these values, the span of accumulated acid deposition in central Europe varies between 50 and 300 Kmol H^+ha. Half of this amount has been deposited after 1959, and one third after 1970.

Natural and Anthropogenic Components of Soil Acidification

The deposited acidity has to be related to rates of natural soil acidification in order to assess its importance for ecosystem changes. Long term annual mean values of the various kinds of proton load (see legend) are given for a range of forest ecosystems with mature stands (timber tree) in North Germany (Figure 1) (Bredemeier 1987). The ecosystem internal proton production which is not directly caused by acid deposition is due to the aggradation of biomass. This process accounts for only 13 of 27% of total proton load with the exception of the oak stand where it amounts to 47%.

The acid load (and acid buffering) for a rotation period of 100 years is compiled (Table 1). Acid deposition amounts to between 50 and 75% of total acid load.

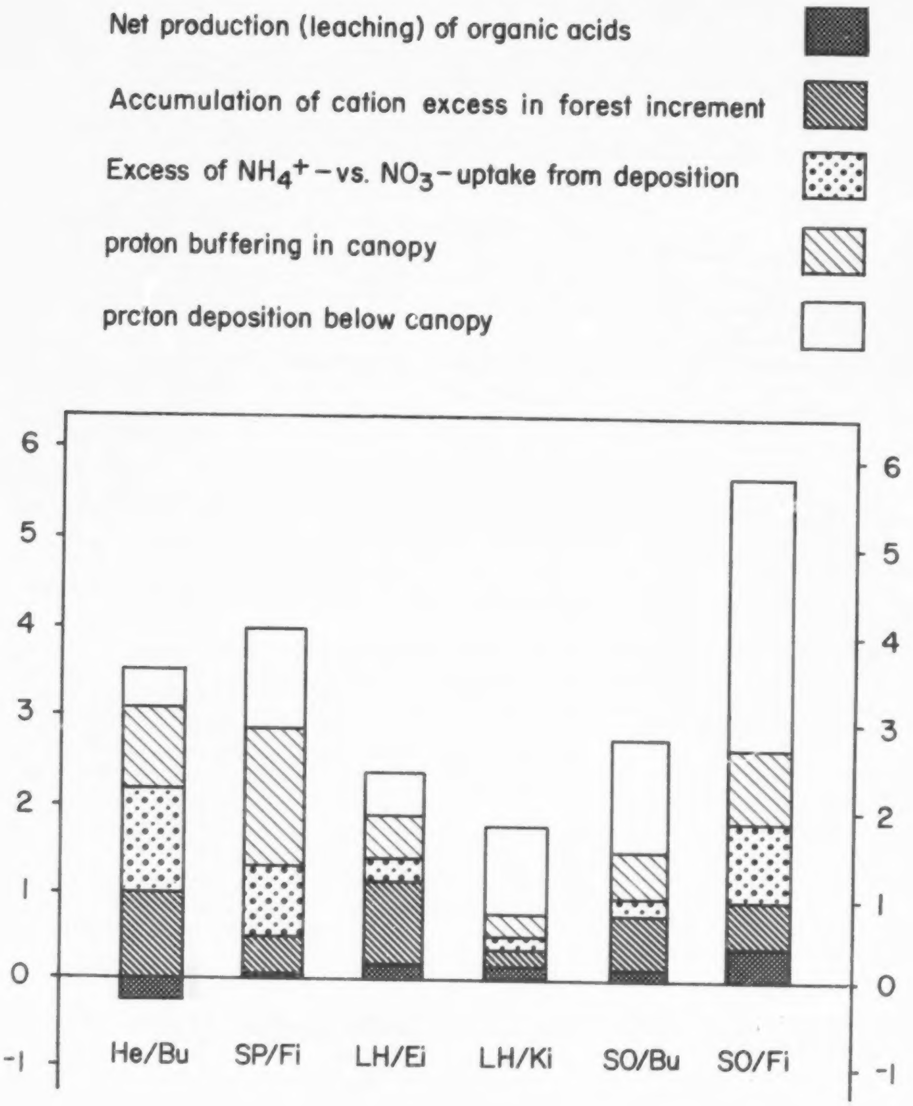

Figure 1.--Mean annual rates of ecosystem internal proton production (INP) and total proton load (GPM) of different forest ecosystems (values in Kmol H^+ Ha^{-1} a^{-1}) (from Bredemeyer 1987).

Table 1.--Acid sources and buffering for a rotation period of 100 years

A.	Acid source	Kmol H^+/ha
1.	Accumulation of cation excess of standing biomass	20 to 40 (beech) (spruce)
2.	Removal of timber	around 30
3.	Decrease in nitrogen storage of soil by nitrate leaching	between 50 and & 100
4.	Acid deposition	between 50 and 300
Sum		between 100 and & 400
B.	Acid buffering in soil (1 m depth)	
1.	Silicate weathering (release of Ca, Mg, K, Na)	between 20 and 100 (200)
2.	Leaching of exchangeable Ca and Mg from cation exchange sites	7 to 700 (sandy soils) (clay soils)

Acid/Base Reactions in Soil

The principles of the acid/base reactions in soil are well known. On the basis of the knowledge available, a series of consecutive buffer ranges has been defined (cf. Ulrich 1986a).

The only process which consumes proton and releases Ca, Mg and K ions is the weathering of silicates. The rate of this process depends upon the kinds and amounts of silicates present and only to a minor extent on pH of the soil. The maximum rate of proton consumption reported in soils rich in weatherable silicates is around 2 Kmol H^+ $ha^{-1}a^{-1}$ at a soil depth of around 1 m. For most German forest soils developed on magmatic and sedimentary rocks poor in silicates the rate is around 0.5 Kmol $H^+ha^{-1}a^{-1}$. This is in the range of soil acidificiaton due to forest increment (cf. Fig. 1). If the harvesting is limited to the stemwood without bark, the acid production remaining in soil is around 0.3 Kmol $H^+ha^{-1}a^{-1}$. In general one can say that for many forests the soil acidification caused by timber harvesting is balanced by silicate weathering.

This means, however, that any additional acid load leads to a decrease in exchangeable bases (Ca, Mg, K). The above calculation leads, therefore, to the estimate that an amount of exchangeable bases equivalent to the accumulated acid deposition (50 - 300 Kmol H^+/ha) has been leached from forest soils or subsoils during the last century; half since 1950, one third since 1970. Assuming 100% base saturation (which is not true, especially for the A horizon of many forest soils), the amount of exchangeable bases in the uppermost m of forest soils varies between 7 (in sandy soils) and 700 (in clay soils) Kmol ion equivalents (IE) per ha (see Table 1). If the initial state was 50% base saturation, the values would be 3.5 to 350 Kmol/ha. The comparison in Table 1 between acid load and acid buffering during a rotation period of 100 years shows clearly that acid deposition must have led to extreme low base saturation in great soil depth in many forest soils.

Present State of Forest Ecosystems

To characterize the present state, data are necessary on the storage of exchangeable Ca (Mg, K) in the soil, on input and output of ions, on the variation of the concentration of nutrients and acids in the soil solution in space and time, and on damage symptoms to the vegetation.

Several representative investigations of the chemical state of forest soils in various forest districts in the northern part of Germany reveal that more than half of the forest soils in this area possess exchangeable pools of Ca + Mg in the rooting zone of the mineral soil (soil depth 50 to 80 cm) below 10 Kmol IE/ha (Ulrich 1987 a). This is at the lower limit of the possible range (cf. Table 1: 7 to 700 Kmol/ha). Base saturation in these soils is around 5% and thus much lower than calculated from soil data analyzed in the 1950's (see above). Input by deposition and output with the seepage water of Ca differ in these soils only slightly. This shows that the exchangeable Ca pool in these soils is, at a very low level of Ca saturation on the exchanger, in a kind of steady state with the rate of deposition of Ca. These soils have lost the capacity to buffer acidity by the exchange of Ca and Mg. The accumulated amount of acid deposition exceeds the Ca storage in these soils by a factor of 5 or more. Acid deposition can be considered as a global titration of bases at the earth surface. For these soils, the titration of exchangeable base cations is completed. These soils are in the aluminum buffer range throughout the rooting zone. The output of acidity (H^+ + ⅓ Al^{3+} + ½ Mn^{2+} + ½ Fe^{2+} + NH^{4+}) from these soils in the long-term mean is slightly higher than the input. As the sulfate balance shows (see Figure 2; for characterization of the ecosystems see Table 2), this is also true for sulfate. This indicates that acidic sulfates (Al hydroxo sulfates), accumulated during a phase with higher base saturation, are now dissolved and leached.

The main anion in deposition and seepage output is sulfate (Figure 2). The rates of sulfate deposition and output as well as the SO_4-S/Cl ratio in sea water is 0,05. This shows that sea-born sulfate is a negligible fraction. In Central Europe, more than 90% of the SO_2-born sulfate is from anthropogenic emissions. The deposited sulfate, originating almost completely from emissions is, as a mobile and conservative anion, the vehicle which carries the acidity (protons, cation acids like Al ions) down the soil profile and the Ca and Mg ions originating from the buffer reactions out of the soil.

The weathering mantle, with the soil at its top, reacts like a cation exchange column: As a consequence of the deposition of acidity, an acidification front moves downward. Preliminary results show that the acidification front in loamy soils lies between 1 and 5 m, in sandy soils it may be below 10 m depth. With continuing acid deposition, large scale ground water acidification in forested areas must be expected.

Table 2.--Characterization of the forest ecosystems of Figure 1

Item	GW/Bu	He/Bu	LH/Ei	SP/Fi	LH/Ki	SO/Bu	SO/Fi	HI/Fi	Wi/FI
location	Gottinger Wald	Harste bei Gottingen	Luneburger Heide	Spanbeck bei Gottingen	Luneburger Heide	Solling BI	Solling FI	Hilskamm	Wingst Westerberg
tree species age (years)	beech 110	beech 95	oak 103	spruce 85	pine 98	beech 135	spruce 100	spruce 14	spruce
soil parent material	lime stone	loess + limestone	glacial sands	loess + sandstone	glacial sands	loess + weathered sandstone		poor sandstone	glacial sands
soil type	Rendzina-Terrafusca	Parabraunerde	Podsol-Braunerde	podsolige Braunerde	Podsol-Braunerde	podsolige	Braunerde	Podsol	Podsol
buffer range A-Hor.	Austauscher	Austauscher	Al	Fe/Al	Fe/Al	Fe/Al	Fe/Al	Fe/Al	Fe/Al
buffer range B-Hor.	Carbonat	Austauscher	Aust./Al	Al	Al	Al	Al	Fe/Al	Al
exchangeable Ca + Mg in 0-50cm [Kmol IA/ha]	1100	200	9	18	6	9	8	6	8
Deposition rate $H^{+}+NH_4$ [Kmol IA $ha^{-1}a^{-1}$]	2.3	2.2	1.6	3.7	2.0	2.8	4.9	1.5	4.5
Deposition rate Ca + Mg [Kmol IA $ha^{-1}a^{-1}$]	1.1	0.7	0.5	1.0	0.7	1.1	1.4	0.8	1.1
depth of output measurement	1 m	0.4 m	1.50 m	0.4 m	1.5 m	1 m	1 m	1 m	1 m
measuring period	1983/84	1982/85	1980/85	1982/85	1980/85	1979/83	1979/83	1984	1984
acidity degree of Seepage water	0%	14%	14%	66%	52%	72%	68%	67%	60%
SO4-S/Cl [g/g] Deposition	1.6	1.7	0.8	2.3	0.8	1.6	2.0	1.7	0.6
SO4-S/Cl [g/g] Output	1.4	1.5	0.9	2.6	1.2	2.0	3.0		0.8
NO_3-N/Cl [g/g] Deposition	0.48	0.52	0.14	0.50	0.19	0.33	0.40	0.50	0.10
NO_3-N/Cl [g/g] Output	0.86	0.79	0.004	0.56	0.005	0.05	0.35		0.22
literature	Meiwes 1983, 1985	Cassens-Sasse 1987	Bredemeier 1987	Cassens-Sasse 1987	Bredemeier 1987	Matzner et al. 1984		Wiedey u. Gerriets 1986	Buttner et al. 1986

Part of acid deposition is buffered by the leaves. The bases needed for the buffering are taken from the soil by cation uptake. This is only one example for the transfer of acid deposition by biological processes. Biological processes show patterns in the soil solution. Acidification pulses can create low pH values and Ca, Mg concentrations and high Al concentrations, resulting in low Ca/H, Ca/Al, and Mg/Al ratios within a few days to weeks. If Al hydroxosulfates are present and dissolved, the Al concentration can rise to >50 mg Al/L. Such processes can vary between soil horizons, according to biological activity and/or the presence of Al hydroxo sulfates. If the Al hydroxo sulfates are already leaches from the top soil, the concentration increase of Al can be most pronounced in the subsoil. They can also vary horizontally within distances of a few meters (for example see Raben 1986). This, and the complexing of Al in the top soil by organic acids, explains why roots in the subsoil are subjected to higher acid stress than in the top soil. It explains also that neighboring trees can show great variation in damage symptoms.

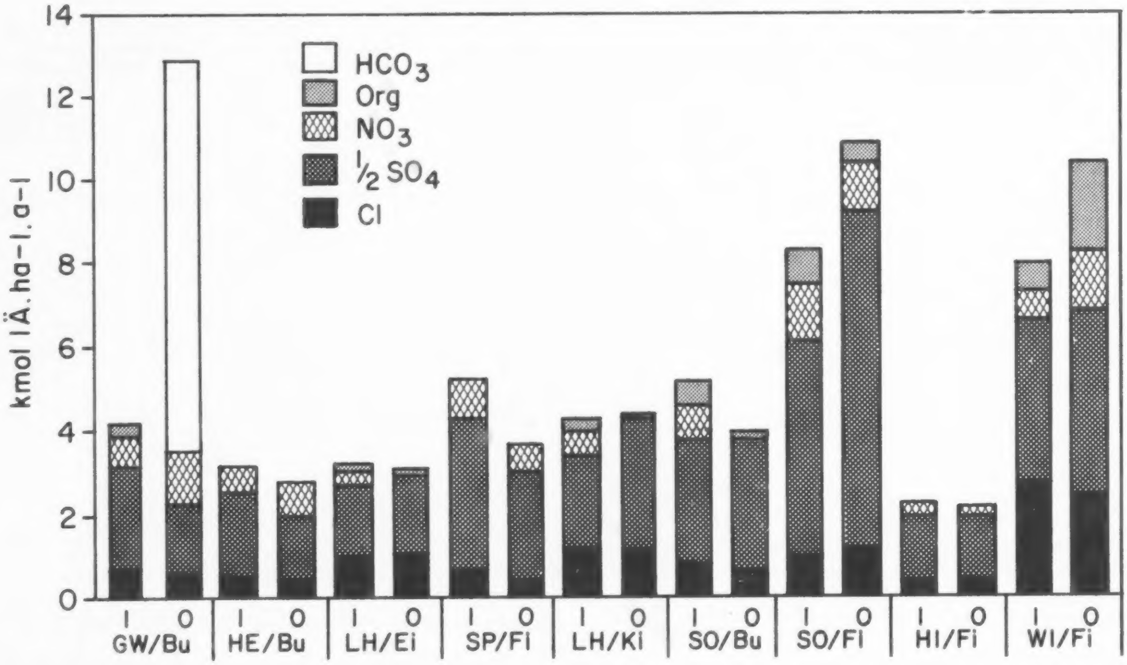

Figure 2.--Anion budget of the ecosystems listed in Table 5 (I = input by deposition, O = output with seepage water).

This spatial variability also exists on the microscale. Aggregate surfaces can be much more acidified than the interior of the aggregates. The acid concentrations in the soil solution in the forest can, therefore, be much higher than in the soil solution obtained after addition of water to a disturbed soil sample (Hildebrand 1986, Hantschel 1987). The long-term trend of the acid stresses parameters in the soil solution shows up in the seepage water collected in the forest in a depth of around 1 m (Figure 2 and 3 for Solling and Harz). The Figures show a distinct trend of increasing acid stress with time to levels of high risk. In the Harz, Lange Bramke, needle yellowing started in spring 1982. For the spruce stand in the Solling fine root biomass data exist since 1982. They show a significant reduction of fine roots from the subsoil, which has now reached the 10 - 20 cm depth layer (Murach 1987). Slight needle yellowing has been apparent for many years.

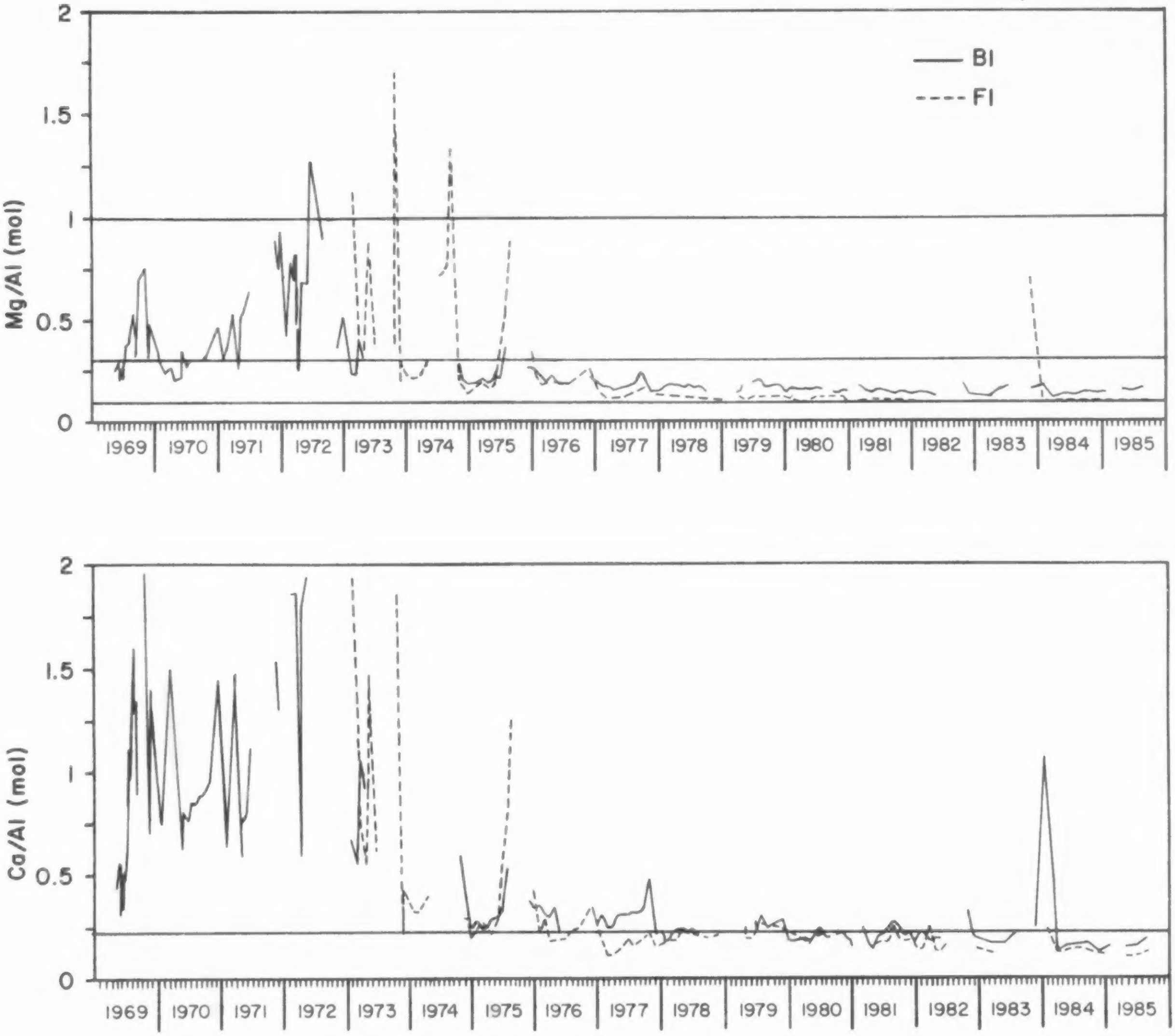

Figure 3.--Ca/Al and Mg/Al molar ratio in the percolation water of the ecosystems SO/Bu and SO/Fi (cf. Table 5) (from Matzner 1987).

Qualification of Acid Stress in Trees

As previously stated, soil acidification leads to a loss of exchangeable bases, and also to an increase in availability of normally only slightly soluble elements such as Al, Fe and heavy metals. According to the fact that the first step in creating cation stress must be the absorption of the cation at a biological surface in competition to other cations, the ratios of competing cations in the soil solution are often suited as stress parameters. Such stress parameters have been defined for *Picea abies* and *Fagus sylvatica*, based on short-term hydroculture experiments (Rost-Siebert 1985, Jorns and Hecht-Buchholz 1985). In nutrient solutions, concentrations of both Al and Pb measured in soil solutions and those of Hg postulated to be available to plants have been shown to inhibit root elongation of both spruce and beech seedlings (Godbold and Hutterman 1986, Godbold et al., 1988a, Neitzke and Runge 1987). In the case of Al, uptake of divalent cations is a more sensitive parameter than inhibition of root elongation. It has been shown that levels of Al, which have little influence on root growth, drastically inhibit the uptake of Ca and Mg, and reduce needle contents of Mg to deficiency levels (Godbold et al, 1988b). Application of these results to field conditions is only possible if the speciation of Al in solution is known. In subsoils poor in organic matter, the Al in soil solution exist predominantly as Al^{3+} and $AlSO_4+$.

Table 3.--Amounts of Al, Ca and Mg in Root tips of *Picea abies* grown for 123 days in nutrient solutions containing 2 μM Al or from fine roots taken from the upper mineral soil at Solling, West Germany; amounts in counts per second ± standard deviation

	-Al			Al			Solling		
Item	Al	Ca	Mg	Al	Ca	Mg	Al	Ca	Mg
Outer hyphal layer	--	--	--	--	--	--	90^{+12}	3^{+1}	n.d.
Hartig net	--	--	--	--	--	--	59^{+26}	4^{+1}	n.d.
Cortex cell wall	11^{+5}	48^{+18}	7^{+1}	197^{+53}	6^{+4}	n.d.	209^{+51}	6^{+1}	n.d.
Stele	n.d.	32^{+12}	45^{+27}	3^{+2}	57^{+9}	3^{+2}	1^{+1}	57^{+13}	1^{+1}

Electron microprobe studies have been carried out both on roots grown under controlled conditions and collected from declining tree stands. Using this technique, it is possible to investigate the distribution of elements within tissues. When the distribution of elements in the cell walls of spruce roots grown in nutrient solutions in the presence or absence of Al are compared (Table 3), it can be seen that in the presence of Al, Mg is absent in both the cortex and stele. In the walls of the cortex cells Al displaces Mg, possibly due to the higher affinity of Al than Mg for negatively charged carboxylate groups. Although Al does not pass through the endodermis it prevents Mg from reaching the stele and hence further transport to needles. In Al treated roots and roots collected from declining spruce trees, the distribution and contents of the elements investigated are extremely similar. Al was found only in the cortex cell walls and Mg was absent in the cortex and only just detectable in the stele. This strongly suggests that the roots have been exposed to the same chemical environment. The ratio of Al to base cations used in this study are often found in forest soils. The presence of a mycorrhizal sheath did not exclude Al from the cortex cells.

In similar studies, roots of spruce seedlings exposed to Pb and those collected from the Harz mountains have been compared (Table 4). Lead contents of cell walls of spruce roots in the Harz exceed those of seedlings exposed to 2 uM Pb for 7 weeks. As Pb concentrations measured in bulk soil solutions rarely exceed 0.7 uM, the high lead contents of the cell wall may be due to Pb accumulation in the rhizosphere, and hence in forest soils, concentrations of toxic elements immediately in contact with root surfaces may exceed those of the bulk soil solution.

The high resolution of this technique may also allow quantification of acid stress in single trees accounting for genetic variability between trees and spacial variability in climate and soils.

Table 4.--Amount of Pb in root tips of *Picea abies* grown for 7 weeks in nutrient solutions containing 2 uM Pb or from fine roots taken from the upper mineral soil at Altenau, Harz, West Germany; amounts in counts per second ± standard deviation

Item	Solution culture	Harz mountain
Outer hyphal layer		9^{+7}
Hartig net		15^{+3}
Cortex cell wall	12^{+12}	15^{+2}
Stele	5^{+2}	3^{+1}

Needle Fall

Investigation of root systems of spruce and beech in several stands in Northern Germany has shown a remarkable change in the vertical distribution of fine roots in the last decades (Murach and Matzner 1987). In spruce, the highest density of fine roots is found in the humus layer and the top 10 cm of the mineral soil. These authors could show that not only is the present root distribution strongly related to the chemical status of the soil, in that the highest root densities are found in soil layers with the highest Ca:Al molar ratios (Fig. 4), but also that there has been progressive retreat of the roots to the upper soil horizons documented over the last five years. The lower Al exposure of roots in the humic layer to that of the mineral soil can be supported by electron microprobe studies (Table 5).

Table 5.--Amount of Al and Ca in root tips of fine roots of *Picea abies* taken from the humus layer or the upper mineral soil at Altenau, Harz, West Germany; amounts in counts per second ± standard deviation

Item	Humus layer		Mineral Soil	
	Al	Ca	Al	Ca
Outer hyphal layer	7^{+2}	3^{+0}	90^{+12}	3^{+1}
Hartig net	13^{+5}	8^{+2}	128^{+44}	4^{+4}
Cortex cell wall	12^{+7}	6^{+4}	209^{+51}	6^{+1}

When the Al and Ca contents of the mycorrhizal and cortex cell walls of roots growing in the humus layer are compared to those of the upper mineral soil, roots from both soil types and similar Ca contents, however, the Hartig net and cortex cell walls of roots from the mineral soil had 10 or 20 times more Al respectively than corresponding tissues from roots growing in the humus layer.

The absence of roots in the deeper soil layer can have serious consequences during conditions of summer drought or in late winter when strong sunlight warms the needles while the ground remains frozen. Such conditions result in a major reduction in water supply to the canopy. Gruber (1986) could show that needle abscission is primarily a mechanical process controlled by the water content of the needles. In an extensive study of the dynamics of needle fall, Gruder (1986) could also show that older needles are constantly shed and replaced by new growth from either apical or dormant buds. Under conditions of water stress, older needles are preferentially shed resulting in crown thinning and the so called "Silver tinsel" syndrome. Water stress may be further exacerbated by erosion of the normally impermeable cuticular by high levels of gaseous pollutants.

Hence, the pattern of needle loss can be explained in terms of the latent effects of soil acidification and extremes of climate.

Acknowledgments

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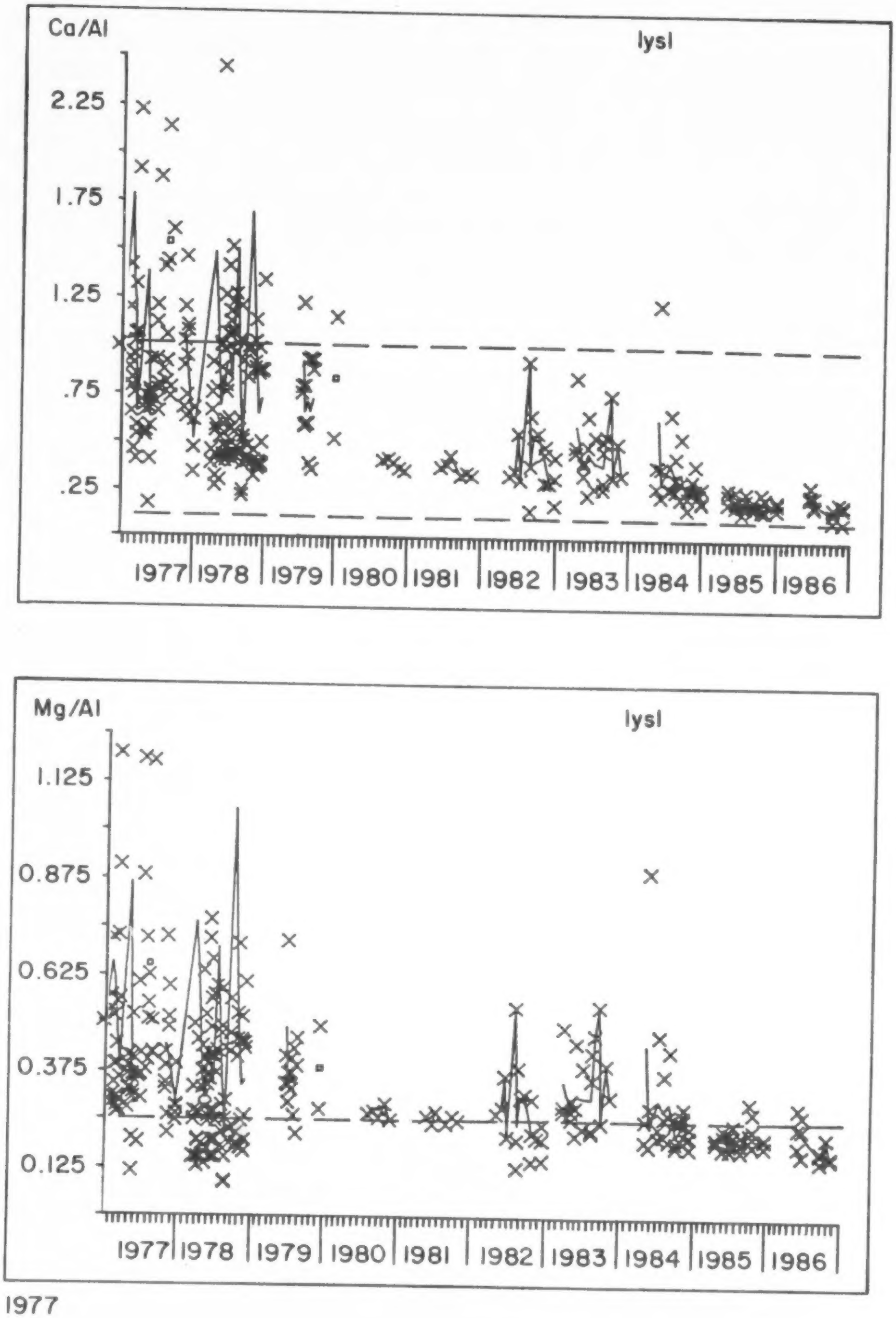

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Figure 4.--Ca/Al and Mg/Al molar ratio in the percolation water of the Lange Bramke watershed (Harz) (Hauhs 1985).

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Culture Techniques to Generate Roots of Red Spruce for Use in Electrophysiological Studies

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Abstract

To provide a reliable, continuous supply of red spruce ***(Picea rubens)*** *roots with characteristics for use in electrophysiological experiments, seedlings were grown in perlite within plastic tree planting tubes from which light was excluded, maintained under controlled environmental conditions in a growth chamber, and provided with nutrients by an automatic irrigation system. Roots generated by these techniques have morphological characteristics that are comparable to those of plants grown in soil; are nonmycorrhizal, a condition necessary for the objectives of this stage of the research; are without algal growth on the surfaces; and have anatomical and physical characteristics needed to meet the technical criteria for measuring membrane potentials of individual cells.*

Introduction

Vigorously growing root tips that meet specific technical criteria are needed to conduct electrophysiological studies and determine membrane potentials of individual root cells. Red spruce *(Picea rubens* Sarg.) roots grown in soil and in several types of potting media vary in their morphological characteristics and vigor, and are covered by particles of inorganic and organic matter that adhere to the musilage layer. Consequently, it is difficult to see cells clearly under the microscope, and few root tips are suitable for electrophysiological studies. Root tips must be firm enough to remain still when microelectrodes are inserted into cells, and cell walls must offer little resistance to penetration by microelectrodes. To meet these criteria, clean, vigorous, actively growing root tips are needed; root tips with primary cell walls, and without secondary walls or suberin--the type of "feeder roots" considered most active in the uptake of nutrients. Roots also must have morphological characteristics comparable to those of soil-grown plants. In addition, because current research is focused upon the physiological mechanisms of ion uptake by the roots themselves, independent of associations with other organisms, the roots must be nonmycorrhizal.

Red spruce roots used in an earlier study (Etherton et al. 1983) were slow-growing primary roots from seedlings maintained on an agar medium. It was difficult to see the positions of microelectrodes within cells, and the roots resisted penetration by microelectrodes, probably because they were suberized. Since then, other techniques were evaluated and included different agar media formulations, hydroponic cultures, and several combinations of pot and potting media. The techniques that evolved provided the type of experimental materials needed to achieve the objectives of the current study and studies planned for the future.

Seed Stratifiation and Germination

Procedures for germinating seeds were based upon principles used earlier for Norway spruce *(Picea abies)* (Romberger et al. 1970); however, the techniques were modified and a stratification step was added. Two Pellon wicks (8-mm X 25-cm) were mounted through drain holes in each 10-cm plastic pot. A circle of fiberglass screen was placed in the bottom, and the pot filled with a mixture of milled sphagnum and No. 4 quartz sand (3:2, v/v). The wicks were kept toward the center and extended about 5 mm above the mounded surface of the medium. Two-hundred dry seeds were distributed over the medium and covered with several layers of cheesecloth that were attached with a rubber band around the upper edge of the pot. The surface was watered, the cheesecloth readjusted to fit tightly, and excess cloth cut from below the rubber band to prevent excessive water loss by evaporation. Each pot was mounted over a 600-ml beaker containing 275 ml of 1/2X modified Ingestad (1962) solution for spruce at pH 4.5. The Pellon wicks functioned to keep the medium and the cheesecloth cover wetted.

Pots were maintained at 4°C for a period of 7 days to stratify the seeds. (If kept under these conditions for more than 7 days, fungus developed on both the sphagnum and seeds, and there was no improvement in germination.) The pots were placed in a growth chamber at a constant temperature of 25°C, and under a 14-hour photoperiod with an illuminance of 3,800 lx provided by cool-white fluorescent lights. Nutrient solutions and beakers were replaced twice weekly. After 10 days in the growth chamber, the cheesecloth covers were removed, and dense beds of uniform, vigorous, green seedlings with strong hypocotyl hooks were present.

Transplanting Seedlings

Seedlings were maintained in the growth chamber until primary roots elongated and cotyledons expanded, after which they were transplanted into 20-cm, cone-shaped plastic tubes (ConeTainers) designed for growing containerized tree seedlings. A potting medium of peat and vermiculite (1:1, v/v) was used. Seedlings were maintained in a greenhouse and received biweekly applications of a commercial, liquid fertilizer (Peters Plant Food). After 2 months in the greenhouse, well-developed seedlings were repotted in modified plastic tubes and placed in a growth chamber.

Modifications of Plastic Tubes

Plastic ConeTainers were painted silver to reflect incident radiation and prevent passage of light through the plastic. A piece of fiberglass screen was inserted into each tube to cover drainage holes. Seedlings were removed from greenhouse culture tubes, the roots were rinsed with water and trimmed to leave a dense root mass, and seedlings were transplanted to perlite in the modified tubes. A silver-painted Teflon square (5.5 X 5.5-cm) with a 5-mm hole in the center and a slot from the hole to an outer edge was slid around each seedling stem and attached with electrical tape to served as a cover for the tube. The Teflon cover also had a 2-mm hole punched 1.5-cm off-center to hold a polyethylene nutrient feed line.

Assembly and Operation of Apparatus

Each modified tube with its seedling was mounted in a 250-ml, clear plastic, graduated cylinder that was cut back to the 190-ml level with an electrically-heated, hot-wire device. A small vent hole was made at the 130-ml level with a flame-heated, No. 1, stainless steel cork borer, and a drain hole was made at the 20-ml level with a No. 5 borer. Each graduated cylinder was supported by a 900-g, 7-cm, Lead Donut placed on its base. A No. 00 Neoprene stopper, fitted with a 6-cm segment of 4-mm glass tubing was inserted into the drain hole and attached to segments of increasing diameters of Tygon tubing to drain overflow solution into a beaker.

Small-diameter, polythylene (Intramedic), nutrient feed lines were connected to individual plastic culture tubes from a stainless steel, 8-port, Drummond Manifold. Autoclaved, 1/2X modified Ingestad (1962) solution for spruce at pH 4.5 was delivered from an Erlenmeyer flask through Tygon and silicone tubing to the manifold. A Masterflex pump system controlled by a ChronTrol microprocessor-based timer operated for 20 seconds every 2 hours and provided a flow of 2.5 ml to each plastic tube. Eight cylinders with tubes were maintained in the growth chamber at 25°C and under a 14-hour photoperiod with an illuminance of 3,800 lx provided by cool-white fluorescent lights. The apparatus was disassembled and cleaned weekly, and most items were autoclaved. When roots were needed for experiments, a seedling was removed from the perlite medium, sample root tips cut-off, and the seedling repotted.

Summary

The techniques described provide a reliable, continuous supply of red spruce roots with characteristics that make them suitable for use in electrophysiological experiments. The roots have characteristics comparable to those of plants grown in soil, and they are nonmycorrhizal. Because of these characteristics, and the absence of algae and other organisms that are present on roots grown by other techniques, the roots are also suitable for metabolic studies that constitute another aspect of the current research.

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Geographic Variation in Needle Morphology of Red Spruce in Relation to Winter Injury and Decline

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Abstract

Variation in morphological characteristics of red spruce needles was examined on a rangewide geographic basis to define the bases for ecological zones of inherent susceptibility to winter injury. The amunt of epicuticular wax on needles was the characteristic most clearly related to measured rates of transpiration and winter injury of red spruce seed sources, and also differed significantly from the amount found on needles of black spruce, a species resistant to winter injury. Potential genetic variation in amount of epicuticular wax could predispose high-elevation populations to winter injury, a pattern that is consistent with observed severity of decline.

Introduction

Winter injury to needles has been identified as a stress factor contributing to the deterioration of red spruce in Eastern North America (Friedland et al. 1984). Damage usually occurs in late winter when periods of cold weather are followed by sudden increases in temperature, or during periods of intense solar radiation that result in heating of needles and a high vapor pressure gradient between the needle surface and the relatively dry surrounding air, allowing water to evaporate through the cuticle (Baig and Tranquillini 1976). Under these conditions, loss of water from the needles cannot be replaced because free water in either the soil or xylem is frozen. The major visible foliar symptom is browning followed by loss of needles from the tips of branches. In most cases, damage is confined to 1-year-old needles (Curry and Church 1952; Friedland et al. 1984). Defoliation can reach 75 percent or more and can lead to death of the tree. Growth of severly injured trees is greatly reduced in the years following injury. Curry and Church (1952) reported a 50-percent reduction in diameter growth 2 years after injury.

Mortality, dieback, and growth decline of red spruce tends to be most severe at high elevations (Johnson and Siccama 1983, 1984). Concentrations of nitrogen and other components in atmospheric deposition are greatest at high elevations, so supplemental atmospheric inputs have been implicated circumstantially as predisposing causal factors of winter damage (Friedland et al. 1984; Nihlgard 1985). However, red spruce is more prone to winter injury than other conifers. Populations of balsam fir, white spruce, and black spruce sympatric with damaged red spruce do not exhibit symptoms even when their branches are close to or intermingling with those of affected red spruce (Pomerleau 1962). Moreover, some needle characteristics of conifers that control the rate of transpiration during the critical winter months vary inversely in their capacity to retard water loss along increasing elevational gradients (Baig and Tranquillini 1976; DeLucia and Berlyn 1984).

Evidence of geographic variation in susceptibility of red spruce to winter desiccation injury in provenance experiments (Morgenstern 1969a,b; Morgenstern and Farrar 1964; Morgenstern and Fowler 1969; Morgenstern et al. 1981) suggests that variation in needle characteristics regulating water loss may be inherent. It is important, therefore, that the range of genetic expression and pattern of physiological development of characteristics that may be negatively affected by anthropogenic factors be evaluated under ambient conditions to fully understand the influence of atmospheric deposition on the relative vigor of spruce. The objective of this study was to quantify variation in morphological characteristics of red spruce needles that have been shown to be associated with winter transpiration rates in other species on a rangewide geographic basis, and to define the physiological and anatomical bases for ecological zones of inherent susceptibility to winter injury.

Methods

The study trees are growing in a red spruce rangewide provenance test planted in 1960 on the Coleman State Forest in Stewartstown, New Hampshire. The plantation has 12 seed sources originating from latitudes ranging from 35°36' N (North Carolina) to 46°37' N (New Brunswick, Canada) and elevations from 46 to 1,615 m. Each seed source is represented by 25-tree plots in each of three randomized blocks. Mortality of trees within seed sources was scored and heights of all surviving trees in the plantation measured in September 1985. Winter injury of all trees in the plantation in 1986 was scored in April on a scale of 1 to 5 corresponding to 0-20 to 80-100 percent of the upper crown showing symptoms. Midpoint values of each class for each tree were used for calculating winter-injury scores of seed sources and for subsequent statistical analyses. Percent of trees injured within seed sources, regardless of severity, was used as a second index of susceptibility.

Measurements of needle morphology and transpiration were made using excised shoots collected from 3 randomly selected trees in each 25-tree plot for a total of 9 trees per seed source (108 individual trees). Morphological needle characteristics of black spruce were measured to provide a direct comparison with a species resistant to winter desiccation injury. The black spruce sample consisted of 2 trees from each of 17 eastern North American seed sources (34 individual trees) growing in a rangewide provenance test at Alfred, Maine, that was planted in 1974. The principal needle characteristics of red spruce seed sources and black spruce examined were:

1. Anatomical development of the cuticular layer of the epidermis.
2. Quantity of epicuticular wax on needle surfaces.

Measurements of several other needle and branch characteristics of both red spruce and black spruce were made to ensure that seed-source differences in winter injury and transpiration rates could eventually be attributed solely to cuticle development and/or amount of epicuticular wax on needles. These characteristics were needle length, needle dry weight as an estimator of needle surface area, needle density (number of needles per cm of branch length), and abaxial and adaxial stomatal density (number of stomates per mm of needle).

Transpiration

The rate of water loss from current-year portions of branches collected from the upper crown of all 108 red spruce trees was measured gravimetrically in late November 1986 (two branches) and mid-March 1987 (two branches). Twigs collected from each tree were recut under distilled water immediately after they were brought in from the field. The twigs were placed upright into test tubes of distilled water and left in a growth chamber under diffuse low light for 72 hours prior to the experiment. The twigs were then removed from the water, blotted, and dried with a stream of warm air for several seconds. The cut ends were sealed with paraffin wax; the twigs were weighed and placed on wire racks on laboratory benches at room temperature. The twigs were reweighed as many times as possible over the next 14.5 hours. Transpiration was measured as the total decrease in weight and expressed as a percent of initial fresh weight. Transpiration of balsam fir twigs collected from 32 trees within each of six geographically distinct populations (three originating from high-elevation [>600 m] montane forests and three from low-elevation [<300 m] forests) growing in a provenance test plantation at Burlington, Vermont, was measured in March 1987 using identical methods.

Cuticle Thickness

Current-year needles of red spruce for examination of cuticle development were collected in late November of 1986. One needle each from the tip, center, and base of a single branch from each of the 108 trees was fixed in cold formalin-acetic acid-alcohol, dehydrated, and embedded. Sections, 10 to 15 microns thick, were cut from the middle one-third of the needle with a microtome, mounted on glass slides, and stained with Sudan III in ethylene glycol after immersion of the tissue in 10 percent chromic acid. Thickness of two visibly distinct cuticular layers was measured with a calibrated Zeiss objective micrometer on a Zeiss microscope at 400 X magnification. Measurements were made at the center of an epidermal cell near the apex of the four needle ridges and averaged to obtain a mean value for each needle. Cuticle thickness of a single needle from a branch from each of the 34 black spruce collected in April 1987 was examined and measured in a similar manner.

Epicuticular Wax

Red spruce epicuticular wax was extracted from 50 current-year needles, using mutliple solvent immersions of short duration, collected from two to four branches from each tree in March 1986 and three branches in March 1987. Black spruce epicuticular wax was extracted from 50 needles from three branches of each tree collected in April 1987. For each species the amount of wax per needle and per gram dry weight of needles was measured by a colorimetric assay developed by Ebercon et al. (1977) and standard curves generated using seed-source composite spruce wax and polyethylene glycol.

Analyses

Differences among red spruce seed sources in all measured variables were tested for significance by analyses of variance. Plot-mean analyses were used for height, mortality, and winter-injury data sets. Individual-tree analyses were used for all morphological needle characteristics and transpiration. Degrees of freedom were 2, 11, 22, and 72 for block, seed source, experimental error, and sampling error, respectively. Correlations were calculated, using seed-source means, between transpiration and winter injury and between those variables and all morphological needle characteristics. Differences between red spruce and black spruce in needle morphology were tested for significance by a series of t-tests. In all cases, means of multiple measurements made within trees were used for statistical analyses.

Results and Discussion

Nearly half (46 percent) of the red spruce in the provenance test plantation suffered some winter injury in 1986. Seed-source differences in winter injury were highly significant (Table 1). In a West Virginia population, more than 75 percent of the trees were injured, and nearly 34 percent of the current-year foliage in the upper crown was killed. Winter injury was correlated with total height ($r = -0.75$), with greater injury in shorter populations. This relationship may reflect the cumulative effect of periodic losses of photosynthetic surface area. Winter injury also was correlated with seed-source mortality ($r = 0.60$) in the plantation during the period 1960-85. It is likely that repeated winter injury was responsible for the death of some of the trees in the most susceptible seed sources. Winter-injury score and percent of trees injured within seed sources were both correlated ($r = 0.60$ and ($r = 0.76$, respectively) with an index of susceptibility to winter desiccation for the same seed sources growing in Ontario, Canada, that was calculated by Morgenstern (1969a) following the winter of 1966-67.

Transpiration

Seed-source differences in transpiration--gravimetric water loss from current-year branches over a 14.5-hour period as a percent of initial weight--were not significant (Table 1), but transpiration was correlated with winter-injury score ($r = 0.62$). Unexplainably, mean water loss from 432 red spruce branches was only 12.9 percent, which was 40 percent lower than mean water loss (18.0 percent) from 192 balsam fir branches--a species that is not known to be susceptible to winter desiccation injury. DeLucia and Berlyn (1984) also reported high rates of transpirational water loss from balsam fir, 18 percent for 14 trees growing at an elevation of 732 m and 23 percent for trees growing at 1,402 m. Nevertheless, winter damage to red spruce appears, at least in part, to be caused by water loss through needle surfaces, though cold acclimation and deacclimation processes also may be involved.

Table 1.--Mean 30-year height, mortality, transpiration, and 1986 winter injury of 12 red spruce geographic seed sources in the Coleman State Forest provenance plantation, Stewartstown, New Hampshire.

Seed source number	Place of origin	Height	Mortality[a]	Transpiration[b]	Winter-injury score	Percent of trees injured
		m				
2019	*Indian Gap, NC*	*5.3*	*34*	*14.2*	*14.6*	*48.8*
2020	*Glade Run, WV*	*5.1*	*29*	*14.6*	*33.8*	*75.6*
2021	*Bear Meadows, PA*	*7.2*	*23*	*13.4*	*7.3*	*42.3*
2022	*October Mtn. State Forest, MA*	*6.2*	*41*	*13.9*	*18.1*	*62.5*
2024	*Upper Jay, NY*	*6.0*	*27*	*13.0*	*9.2*	*45.8*
2027	*Pillsbury State Forest, NH*	*6.2*	*27*	*11.6*	*14.2*	*50.0*
2030	*Amherst, ME*	*6.5*	*25*	*12.7*	*10.6*	*40.8*
2032	*Valcartier Forest Exp. Stn., PQ*	*6.5*	*14*	*12.8*	*2.3*	*23.0*
2100	*Sheet Harbour Waters, NS*	*6.5*	*25*	*12.2*	*8.4*	*48.0*
2101	*Corberrie, NS*	*6.2*	*24*	*12.4*	*10.2*	*30.0*
2103	*Acadia Forest Exp. Stn., NB*	*7.3*	*12*	*12.8*	*6.7*	*34.9*
2505	*Acadia Forest Exp. Stn., NB*	*7.2*	*20*	*11.8*	*7.3*	*43.6*
F-ratio		*7.71*[c]	*3.86*[c]	*1.29*	*3.67*[c]	*4.45*[c]

[a] *Number of trees that died between 1960 and 1985 (75 planted).*

[b] *Gravimetrically measured water loss of current-year branches as percent of initial weight.*

[c] *Differences among seed sources significant at the 1 percent level of probability.*

Intraspecific Needle Morphology

Significant seed-source variation in winter injury was accompanied by variation in several characteristics of red spruce needle and branch morphology that could be involved in control of water loss (Table 2). Southern seed sources from high elevations--North Carolina and West Virginia--had the lowest needle density (needles per cm of twig length), but their needles weighed the most, a good indication that they have the highest individual needle surface areas (Ohmart and Thomas 1986). Needle density was negatively correlated with both transpiration and winter-injury score (Table 3). The significant negative correlation between needle density and transpiration was unexpected because a greater number of needles should be associated with a greater total needle surface area for evaporative water loss from individual branches. However, low needle density may allow greater circulation of dry air around individual needles and penetration of irradiance that would elevate needle surface temperature.

Stomatal density (number of stomates per mm of needle length) was highest on needles of southern sources except for West Virginia, and was significantly correlated (adaxial surfaces) with transpiration but not winter injury of seed sources (Table 3). Stomatal density was correlated ($r = 0.73$ abaxial; $r = 0.62$ adaxial) with seed-source winter-injury scores based only on the 108 sample. This suggests that water may pass through stomates during late winter when damage is thought to occur. A greater number of stomates per unit surface area may be an inherent characteristic of high-elevation populations. A high capacity for gas exchange would be an important adaptation of high-elevation plants growing in an environment with a short growing season.

Conspicuously absent was any significant seed-source variation in thickness of the cuticle of red spruce needles (Table 2). The cuticle of needles is considered the single most important structure enabling plants to withstand conditions of environmental stress at high elevation sites as it reportedly plays a significant role in controlling the rate of cuticular transpiration, especially during the critical winter months (Baig and Tranquillini 1976). Wardle (1971) suggested that the altitudinal limit of tree growth is determined by the inability of tissue to fully mature in terms of the production of lignin, cuticle, and epicuticular wax, with death occurring as a result of desiccation, usually during the winter. Baig and Tranquillini (1976) found that the thickness of needle cuticle of stone pine (*Pinus cembra* and Norway spruce (*Picea abies*) decreased with increasing elevation in the Austrian Alps. They also reported an inverse relationship among cuticle thickness and rate of cuticular transpiration. DeLucia and Berlyn (1984) also established a clear relationship between needle cuticle thickness, elevation, and the rate of cuticular water loss of balsam fir growing on Mt. Moosilauke in the White Mountains of New Hampshire. Cuticle thickness of needles from red spruce geographic seed sources, however, was not correlated with winter injury or transpiration of those sources (Table 3). This result supports the conclusion of Baig and Tranquillini (1976), DeLucia

Table 2. Needle morphology of red spruce geographic seed sources

Seed source number	Morphological trait								
	Needle length	Needle weight	Needle density	Stomatal density (adaxial)	Stomatal density (abaxial)	Epicuticular wax	Cuticle[a] (outer layer)	Cuticle [a] (inner layer)	Cuticle[a] (combined layers)
	mm	mg/ needle	Needles/ cm stem	Stomates/ mm	Stomates/ mm	mg/g dry weight			
2019	9.9	3.6	17.2	51	80	8.2	1.2	2.4	3.6
2020	9.9	3.2	16.9	43	74	7.8	1.3	2.4	3.6
2021	9.6	2.7	22.2	48	82	10.0	1.2	2.7	4.0
2022	10.3	2.8	20.5	48	81	9.2	1.2	2.6	3.8
2024	10.0	2.7	21.3	41	70	8.9	1.4	2.4	3.7
2027	9.4	2.6	21.4	43	76	10.2	1.3	2.5	3.8
2030	9.6	2.8	20.9	42	77	10.0	1.2	2.5	3.7
2032	10.5	3.0	19.9	38	66	9.4	1.2	2.5	3.7
2100	9.5	2.8	21.0	40	71	9.4	1.2	2.4	3.6
2101	9.7	2.7	20.4	42	76	10.3	1.2	2.7	3.9
2103	9.8	2.9	22.8	38	68	10.0	1.3	2.7	4.1
2505	10.7	3.1	20.9	39	69	9.9	1.2	2.3	3.6
F-ratio	1.07	2.56[b]	5.92[c]	3.28[c]	2.68[b]	4.66[c]	0.49	0.85	0.68

[a] Thickness in microns.

[b] Differences among seed sources significant at the 5 percent level of probability.

[c] Differences among seed sources significant at the 1 percent level of probability.

Table 3.--Correlations (coeficient r) between needle morphology of red spruce geographic seed sources and transpiration, and between needle morphology and winter injury.

Morphological trait	Transpiration	Winter injury	
		Winter-injury score	Percent of trees injured
Needle length	.10	-.12	-.08
Needle weight	.54	.30	.22
Needle density	-.64[a]	-.67[a]	-.48
Stomatal density (adaxial)	.6[illegible][a]	.38	.44
Stomatal density (abaxial)	.42	.36	.39
Epicuticular wax	-.79[b]	-.66[a]	-.64[a]
Cuticle thickness (outer)	.04	.23	.24
Cuticle thickness (inner)	.04	-.21	-.35
Cuticle thickness (combined)	-.10	-.35	-.37

[a] Significant at the 5 percent level of probability.

[b] Significant at the 1 percent level of probability.

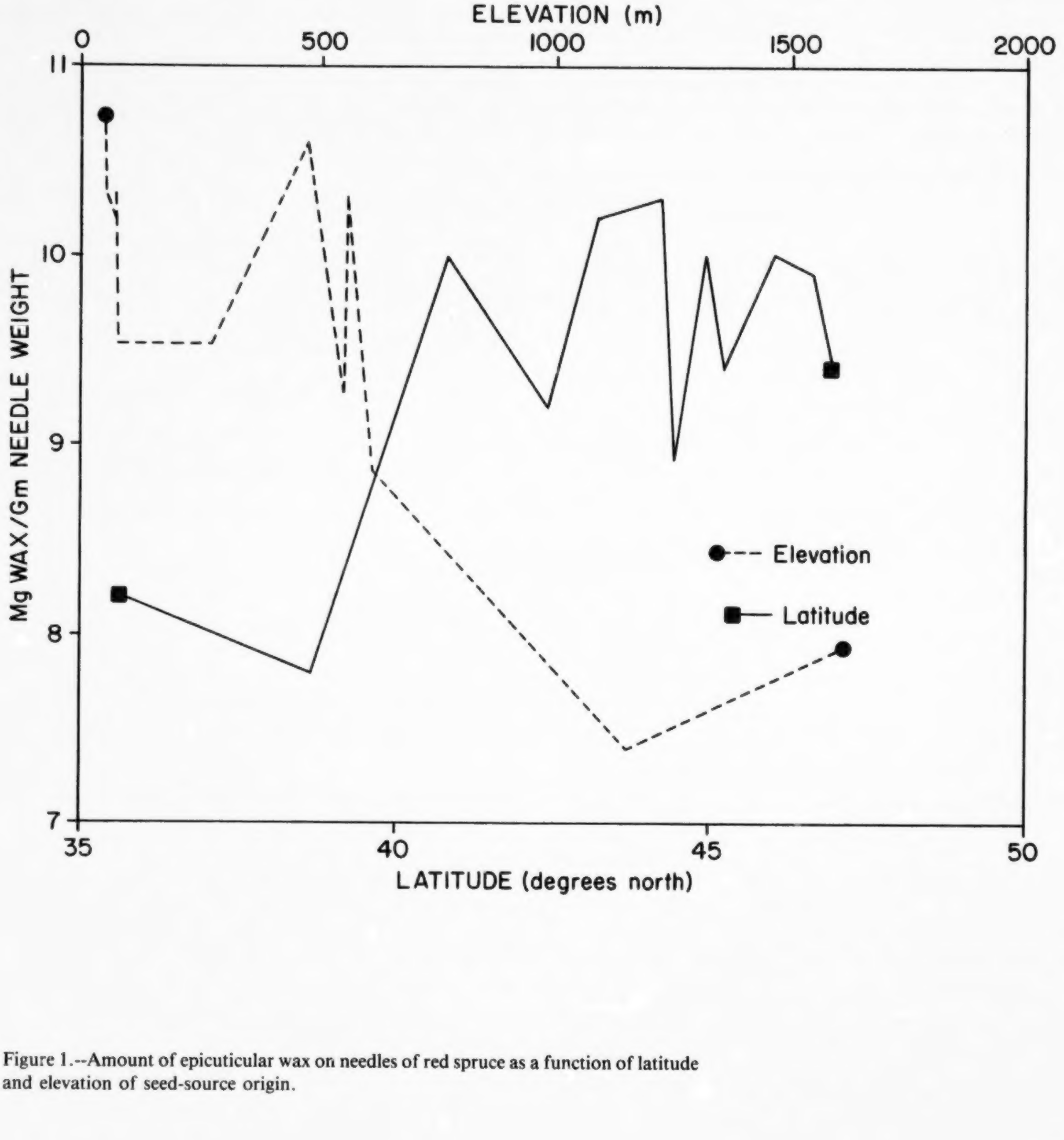

Figure 1.--Amount of epicuticular wax on needles of red spruce as a function of latitude and elevation of seed-source origin.

and Berlyn (1984), and Wardle (1971) that cuticle maturation and development is regulated primarily by the length of the growing season and cumulative seasonal energy input, and would not, therefore, be expected to vary extensively when trees are growing in a common environment.

Epicuticular wax is known to play an important role in reducing water loss from plant tissue. Jeffree et al. (1971) theoretically calculated that occlusion of the epistomatal chambers of Sitka spruce by structural waxes could be expected to reduce transpiration by two-thirds. Heavy cuticular wax on foliage is associated with glaucousness, so another potentially important effect may be the reduction of leaf temperature caused by the reflective properties of waxes (Clark and Lister 1975; Reicosky and Hanover 1978). The amount of epicuticular wax on red spruce needles differed significantly amount seed sources (Table 2). Red spruce from seed sources originating in the southern portion of the range and high elevations had the least amount of epicuticular wax on their needles (Fig. 1). Amount of epicuticular wax also was significantly negatively correlated with transpiration and winter-injury scores of the seed sources (Table 3), and appears to be the primary heritable morphological characteristic (of those measured) reponsible for differential water loss from needles within the species.

Interspecific Needle Morphology

The resistance to winter desiccation reported for red spruce-black spruce putative hybrids and pure black spruce has been attributed

Table 4.--Comparative needle morphology of red spruce and black spruce.

	Red spruce			Black spruce				
Morphological trait	Mean and standard error	Range of seed source means	Range of individual trees	Mean and standard error	Range of seed source means	Range of individual trees	t-value	Level of significance[a] (P)
Needle length, mm	9.9 + 0.10	9.4 - 10.7	7.6 - 13.4	10.4 + 0.25	8.2 - 13.3	7.5 - 14.6	2.17	.05
Needle weight, mg/needle	2.90 + 0.053	2.56 - 3.55	1.87 - 4.66	3.47 + 0.104	2.52 - 4.30	2.06 - 4.67	5.14	<.001
Needle density, needles/cm of stem	20.5 + 0.29	16.9 - 22.8	12.3 - 29.4	15.6 + 0.39	12.9 - 19.3	12.2 - 21.7	8.67	<.001
Stomatal density (adaxial), stomates/mm	42.7 + 0.75	38.0 - 52.0	26.0 - 68.0	35.7 + 1.34	24.0 - 43.0	22.0 - 54.0	4.58	<.001
Stomatal densisty (adaxial), stomates/mm	74.3 + 1.12	66.0 - 82.0	48.0 - 104.0	70.5 + 1.88	56.0 - 81.0	44.0 - 98.0	1.68	NS
Epicuticular wax, mg/needle[b]	0.031 + 0.0006	0.028 - 0.033	0.014 - 0.050	0.046 + 0.0015	0.035 - 0.056	0.024 - 0.068	11.31	<.001
Epicuticular wax, mg/g dry weight[b]	10.7 + 0.15	9.0 - 11.5	5.9 - 15.3	13.3 + 0.35	10.1 - 15.8	8.6 - 18.3	7.71	<.001
Epicuticular wax, mg/g dry weight[c]	14.7 + 0.21	12.4 - 15.9	8.8 - 20.9	18.4 + 0.48	13.9 - 21.8	11.7 - 25.3	8.06	<.001
Cuticle thickness (outer layer, microns)	1.26 + 0.017	1.20 - 1.41	0.95 - 1.92	1.40 + 0.049	0.93 - 1.84	0.93 - 1.87	3.44	<.001
Cuticle thickness (inner layer, microns)	2.75 + 0.035	2.31 - 2.75	1.52 - 3.58	2.18 + 0.079	1.83 - 2.80	1.67 - 3.20	7.38	<.001
Cuticle thickness (combined layers, microns)	3.75 + 0.040	3.52 - 4.07	2.62 - 4.95	3.58 + 0.105	2.77 - 4.28	2.77 - 4.88	1.82	NS

[a] Significance of differences between species

[b] Wax weight based only on 1987 red spruce needle collections for inter-specific comparisons.

[c] Polyethylene glycol 4000 standard curve used for wax weight determinations.

to a heavier layer of epicuticular wax on needles than that found on needles of red spurce (Morgenstern 1969a), but that premise was based on observation, not measurements. The yellow-green foliage of red spruce does not have glaucous wax, and the average amount of epicuticular wax extracted from needles of 108 red spruce in 1987, 10.7 mg wax/gm dry weight of needles, was only 80 percent of the average amount extracted from needles of 34 black spruce, 13.3 mg wax/gm dry weight (Table 4). On a per-needle basis, red spruce had only 67 percent as much epicuticular wax as black spruce. The amount of epicuticular wax on red spruce needles, 14.7 mg/gm dry weight based on a polyethylene glycol standard curve, was 55 percent of the average amount found on balsam fir needles, 26.4 mg wax/gm dry weight, by DeLucia and Berlyn (1984).

Almost all of the other morphological needle characteristics of red spruce and black spruce also differed significantly between the two species (Table 4). Of these, only the difference in stomatal density on adaxial needle surfaces is likely to have any influence on species differences in susceptibility to winter desiccation injury. Black spruce had heavier needles (possibly a greater surface area) than red spruce, but red spruce needle weight was positively correlated, though not significantly, with transpiration. Similarly, red spruce had a greater needle density than black spruce, but needle density was negatively correlated with transpiration and winter injury of red spruce seed sources. Black spruce had a thicker outer cuticular layer than red spruce but a thinner inner cuticular layer. Moreover, thickness of the cuticle was not related to differential susceptibility to winter injury of red spruce seed sources.

Conclusions

The resistance of black spruce to winter injury and the extreme vulnerability of red spruce cannot be explained by differences in the amount of epicuticular wax on needles. Some black spruce that have never been injured had less epicuticular wax than some red spruce from the most susceptible seed sources. The chemical composition of epicuticular waxes on needles could be more important in explaining interspecific variation in susceptibility of conifers to winter desiccation injury. The form and spatial distribution of wax deposits on foliage are determined principally by the chemical composition of the wax exudates. Waxes with a high n-alkane content tend to form crystalline wax deposits, giving leaves a rough surface (Chambers et al. 1976). The rough surface reflects a greater proportion of the incident radiation, thereby lowering leaf surface temperature and, hence, the vapor pressure gradient. Moreover, n-alkanes, with no functional groups, have the closest packing of surface methyl groups so that leaf waxes with high percentages of alkanes, particularly those with high carbon numbers, are less wettable and more resistant to penetration by polar substances (Holloway 1969). In a separate study, n-alkanes from epiticular wax from each of the 108 red spruce trees have been quantitatively analyzed by gas-liquid chromatography. The predominant alkanes of all those trees are in the mid-number carbon range (C_{23} to C_{27}) in chain length. Black spruce epicuticular wax, in contrast, was reported by Corrigan et al. (1978) to have primarily long chain alkanes (C_{31}, C_{33}, and C_{35}) and should be more resistant to water passage.

Intraspecifically, the amount of epicuticular wax found on red spruce needles was clearly related to transpiration and winter injury of geographic seed sources. The quantity of epicuticular wax on foliage of several plant species has been found to increase with enhanced absorption of ultraviolet radiation (Steinmuller and Tevini 1985), and the amount of wax on needles of eastern white pine increased during exposure treatments of ozone (Trimble et al. 1982). As a result, quantity of epicuticular wax might be expected to vary phenotypically along elevational gradients with the greatest amounts found on needles of trees growing at the highest elevations. Results of this study of seed sources in common garden, however, suggest that there is potential genetic variation in amount of epicuticular wax on needles of red spruce that could, independently of the exacerbating effects of atmospheric deposition, predispose high-elevation populations to winter injury, a pattern that is consistent with observed severity of decline. On the other hand, epicuticular waxes of conifer needles subjected to air pollutants, particularly sulfur dioxide, undergo dramatically accelerated structural degradation and weathering (Crossley and Fowler 1986; Huttunen and Laine 1983; Percy and Riding 1978). Disruption of wax integrity in those populations of red spruce that are already prone to excessive winter transpiration because of inherently low amounts of epicuticular wax on needles may make them even more vulnerable to winter injury.

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Silvicultural Research on Declining Stands of Spruce and Fir in Bavarian Forests

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Abstract

Visible damage of German forests, a result of forest decline, increases with the age of the trees. Therefore, mainly older stands are subject to field research work. For the rest of the ecosystem, however, the early young phases of forests are at least as important.

*Detailed long term studies on natural regeneration and plantation forestry will provide information on abnormal development of regeneration in declining stands of spruce and fir (**Picea abies** and **Abies alba**). Long term observation of other trials also enables us to develop adequate thinning regimes for younger disturbed stands.*

Natural Regeneration

Damage of Older Stands

When we started investigations on natural regeneration in 25 stands of mixed forests in the Bavarian alps in 1976 (Burschel et. al. 1985), old trees were in good health. Ten years later, they were heavily damaged. Dead trees were found more often in stands with close spacing. Stands with wider spacing showed severe symptoms of decline as well, but there was neither reduction of increment nor mortality.

Consequently, trees of stands with wider spacing were more vital and resistant towards external disturbance that those of stands with close spacing (Mosandl and El Kateb 1988).

Seed Production

During the last ten years seed production was observed in the same stands mentioned above. Table 1 shows for one stand the average of 30 seed traps of 0,25 m^2 each. The main results are summarized as follows:

- All tree species have produced seeds during the last 10 years
- The rate of germination was high
- The rate of germination was positively correlated with the seed density
- The quality of the seeds was not reduced after the occurrence of forest decline in 1981

Samples of beech seeds in Lower Franconia, the northwestern part of Bavaria, showed similar results with no difference in seed quality of healthy and heavily damaged trees (Burschel et. a. 1986)

Seedling Density and Growth

Over the last ten years, density and growth of seedlings were observed in 2500 plots of 1 m^2 size with the following results (Mosandl and El Kateb 1988):

- Seedlings have the best chances of survival under semi-shade — conditions (with 40% canopy closure), indicated by the highest density of plants. Here the density of seeds is high enough, competing ground vegetation is buffered, and the amount of light is sufficient
- Occuring damage to fungi are of minor importance (Mosandl and Aas 1986)
- The limiting factor for the growth of seedlings is deer, roe and chamois
- There was neither reduction of the rate of survival nor of the growth of the young seedlings after the occurrence of forest decline in 1981

Plantations

Experiments of split-plot design were initiated in 1985 in three severely damaged forest regions of Bavaria (Fichtelgebirge, Frankenwald, Kalkalpen) to answer the following questions (Mosandl and Burschel 1986):

- Is the process of natural regeneration undisturbed
- What are the best species for afforestation
- To what degree can the conditions for regeneration be improved by opening the crown canopy, by weeding or fertilization and what kind of interactions exist between these measures

After three years of observation we can give the first recommendations:

- All planted tree species grow in the areas of forest decline. They do not show the same symptoms as the old trees. Therefore, all tested species can be utilized for afforestation
- More important than the species is the quality of the plants; softwall-container plants had the highest survival rates
- So far, weeding had no influence on the rate of survival
- The highest rates of survival were always found in semi-shade conditions under a loose canopy closure of the old trees. Hence it is better to plant under the open canopy of the damaged old trees than on a clear-cut area.

Thinning in damaged young stands

In 1984, the Institute of Silviculture started investigations in young stands suffering from forest decline (Burschel, Huber and Weber 1986). Important results for the development of adequate silvicultural treatments are:

- Young stands under the canopy of old trees are less damaged than comparable stands without canopy shelter

Table 1.--The seed production in the last 10 years in a dense 120 year old mixed mountain forest in the alpine region of Bavaria ($42\ m^2$ basal area: 33% spruce, 32% fir, 19% beech, 11% maple and 5% other species).

Seed Year 1. Sept. to 31. Aug.	Spruce			Fir			Beech			Maple		
	Seeds per m^2	Viable seeds per m^2	Germination %	Seeds per m^2	Viable seeds per m^2	Germination %	Seeds per m^2	Viable seeds per m^2	Germination %	Seeds per m^2	Viable seeds per m^2	Germination %
1976/77	25	9	36	68	24	35	<1	0	0	4	<1	11
1977/78	260	83	32	5	<1	8	53	22	42	47	16	35
1978/79	5	0	0	1	0	0	<1	0	0	2	<1	13
1979/80	2	0	0	17	7	38	0	0	-	7	2	35
1980/81	59	18	30	103	33	32	0	0	-	6	<1	4
1981/82	2	<1	7	<1	0	0	0	0	-	42	22	53
1982/83	56	17	31	11	3	27	<1	0	0	3	0	0
1983/84	3	2	52	5	2	28	<1	0	0	17	<1	1
1984/85	2	<1	36	5	2	34	6	4	58	39	10	26
1985/86	1	<1	22	2	<1	21	0	0	-	12	2	20
76-86	415	130	31	218	70	32	61	26	43	173	55	32

- In 1984 predominant trees were damaged more seriously than suppressed trees (which might be explained by the higher exposure to polluted air)
- In 1986, only two years later, the situation has changed completely (Table 2). The predominant trees have recovered, while the protected suppressed trees were damaged even more. Tough dominant trees are affected first, they are more vital and recover more quickly than suppressed trees.
- For this reason it was not surprising that promoting the dominant trees in thinning operations reduced the damage (Fig. 1)
- The damage was also reduced after fertilizing with magnesium and nitrogen (Fig. 1)

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Table 2.--The distribution of damages (%) in different social classes in 1984 and 1986 in a 30-year-old spruce stand in the Bavarian Forest (from Huber and Weber 1988).

	Damage class--1984			Damage class--1986		
Item	0 + 1	2	3 + 4	0 + 1	2	3 + 4
Predominant trees social class I	10	29	61	12	38	50
Codominant trees social class 2 + 3	15	18	67	14	30	56
Suppressed trees social class 4 + 5	54	21	25	22	12	66

Damage class 0 + 1: needle loss up to 25%, light yellowed old needles

Damage class 2: needle loss 26% to 60%, intensive yellowed old needles

Damage class 3 + 4: needle loss more than 60% and dead, intensive yellowed old and young needles

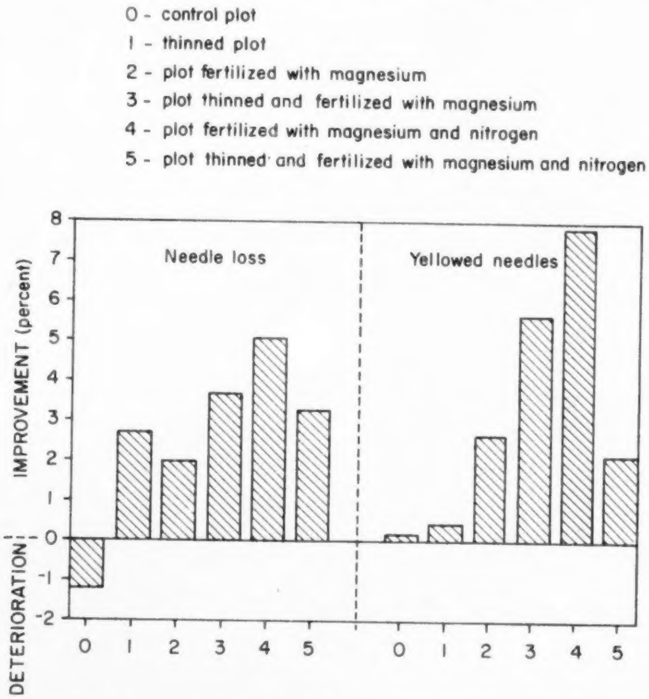

Figure 1.--Single year effects of thinning and fertilizing in a 20-year-old damaged spruce stand in eastern Bavaria (from Huber and Weber 1988).

Role of Ions in the Etiology of Spruce Decline

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Abstract

An investigation of the soil and fine roots at eight locations across northern New England indicated that the relative acidity of humus and mineral soil, and the Al:Ca ratio of the fine roots of spruce and fir growing in those layers, was similar to that observed in spruce-fir stands in Germany. At Mount Abraham, Vermont, where trees are dying at an elevation of 1000 m, aluminum ions in the cortical apoplast of fine roots from the humus exceeded calcium ions by 3:1, a condition associated with severe forest damage in Germany. At all other locations, the Al:Ca ratio was <1 in fine roots of the humus layer, but in the few fine roots of the mineral subsoil the Al:Ca ratio was often ≥ 1. This may threaten mature trees at those sites in the future.

Introduction

Over the past several years, declining health of forest trees throughout central Europe has caused much concern (Schutt and Cowling 1985). The decline phenomenon has been called "Waldsterben." The relationship of this sudden apparent loss of tree health to the stresses of air pollution created by the 20th century economy has been discussed at length by governments and the scientific community. Although no definite conclusions have been reached about the actual impact of air pollution and atmospheric deposition over large geographical areas (localized, acute effects of pollution on plant health is a well-known fact), the possibility clearly exists that forests of central Europe and eastern North America are at risk from air pollutants.

Awareness that a fatal tree disease was developing in the spruce-fir forests of Germany began in the mid-1970's with descriptions of a dieback and decline of silver fir (***Abies alba*** Mill.), sometimes referred to as "fir dying." Trees with dying crowns had a marked decrease in sapwood basal area (portion of the transverse area of the secondary xylem that is functional sapwood) in the lower stem, and a marked increase in wetwood in the lower stem and upper secondary roots (Bauch et al. 1979; Brill et al. 1981; Fruwald et al. 1981). The wetwood of fir is initiated by wounds and involves the infection of exposed wood by bacteria that produce organic acids (acetic, propionic, and butyric), which act on parenchyma cells in sapwood. The spread of wetwood into sapwood was restricted to trees of low vitality, and was not considered the cause of "fir-dying," but a later stage of the disease syndrome. Firs with dying crowns and decreasing sapwood basal area due to wetwood had been declining in cambial activity since the 1950's, long before crown symptoms were observed.

Dendroclimatological studies indicated that this suppression of cambial growth was not related to weather patterns (Eckstein et al. 1983).

By the early 1980's, a dieback and decline syndrome was observed in Norway spruce (***Picea abies*** (L.) Karst), though the symptoms were not as pronounced as in silver fir. However, spruce accounts for 40 percent of the commercial forest in West Germany, fir only about 2 percent. A strong national research program was initiated to investigate the West German forest decline syndrome, sometimes called "forest-dying." The possible influence of air pollution was implicated in many studies, and mechanisms of direct effect on the crowns and indirect effect through the soil were considered.

One mechanism considered was the accelerated release of Al^{3+} ions from soil solids into the soil solution, and its possible harmful effects on mature trees (Bauch 1983; Ulrich 1983). Absorbing fine roots from humus and mineral soil were collected from healthy and diseased trees at healthy and damaged sites. The cortical apoplast and primary xylem were observed by LAMMA (laser microprobe mass analysis) and EDXA (energy dispersive analysis of X-rays) to compare relative amounts of Al to major nutrient cations K, Ca, Mg (Bauch and Schröder 1982; Stienen et al. 1984; Bauch et al. 1985a). Where damage occurred, Al in fine roots was not markedly greater than in healthy stands, but Ca and Mg were markedly reduced, and K remained the same. Thus, Al did not seem toxic, but it might interfere with the uptake of Ca and Mg by interference with exchange in the apoplast.

Studies with the stable isotope $^{44}Ca^{2+}$ indicated that at pH 4, Al^{3+} in equimolar concentrations to Ca^{2+} could reduce Ca uptake so that the Al:Ca ratio in fine roots was ≥ 1 (Schröder et al. 1988). Adding Ca^{2+} to the solution partially restored the uptake of Ca. Similarly, liming restored a more favorable Al:Ca ratio in the fine roots of humus, but not in the fine roots of the mineral soil (Bauch et al. 1985b). A slowing of the decline of cambial growth also was observed following liming. A partial reversal of damage was seen by adding Ca and Mg in seedlings (Stienen and Bauch 1987).

The purpose of this study was to determine the Al:Ca ratio in fine roots of the humus and mineral subsoil of spruce-fir stands across northern New England, and to compare the results with those from similar studies in spruce and fir stands in Germany.

Materials and Methods

Eight spruce-fir stands were sampled across northern New

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England beginning at an elevation of 1000 m on Mount Abraham in Vermont, where canopy spruce are dead and dying, moving eastward across New Hampshire and Maine, and ending at an elevation of 100 m in Beddington Maine, where canopy spruce were uniformly healthy. A brief description of trees at each sample location is found in Appendix A. At each location, two red spruce, (***Picea rubens*** Sarg.) trees and two balsam fir (***Abies balsamea*** (L.) Mill) trees were sampled from the canopy. One tree in each pair had a relatively healthy crown, the other a thinning crown. At each tree a secondary root (2 to 3 cm in diameter) was exposed and collected with attached fine roots and associated soil samples (humus and mineral soil). Roots and soil were placed in labeled plastic bags for transport and storage at -18° C until used. The trees were then felled and stem sections collected at the base, 1.4 m above ground, midbole, and lower crown for wood analysis (Shortle and Bauch 1986). Branches were taken from the 6th and 7th whorl from the top of each tree for foliar analysis.

Soil samples were used to determine pH as an indicator of relative acidity of the humus, which was the primary rooting zone of spruce and fir, and the mineral subsoil, in which few fine roots of spruce and fir were found. Standard German methods were used (Meiwes et al. 1984). The soil samples collected at Mount Abraham and Beddington were oven-dried (55°C) and sent to Germany for equilibrium soil solution analysis at the University of Gottingen (Meiwes et al. 1984).

Fine roots used for analysis of the cortical apoplast were freeze-dried, embedded for electron microscopy, and cut dry with a glass knife to yield 1- μm sections for analysis (Stienen 1985; Stienen and Bauch 1987). Element analysis was done with EDXA (energy dispersive X-ray analysis) and automatic data management for relative element concentration comparisons. From every tree/soil layer combination, three roots were measured (eight measurements/root taken in the 2-4 row of primary cortical cells); and the mean and confidence limits were calculated from the resulting 96 observations per location per soil layer.

Fine roots (approximately 0.2 mm in diameter) used to determine the molar ion concentration were oven-dried (55°C) to yield samples of at least 20 mg (60 to 100 fine roots/mg) from the humus layer in 1985. Yields of fine roots from mineral soil were only a few milligrams in the 1985 sample. Spruce were resampled at three locations in 1986 to obtain yields of at least 10 mg dry fine root tissue from mineral soil as well as from humus. A new location, Howland, Maine, was added in the 1986 sample. The method of Ca analysis was changed from atomic absorption spectroscopy (AAS) to ion chromatography (IC).

Ca, Mg, and Mn were determined by AAS on nitric/perchloric acid digests of 10-mg samples of fine roots (Shortle and Bauch 1986). Al^{3+}, Ca^{2+}, Mn^{2+}, Fe^{2+}, Zn^{2+}, Cu^{2+}, Co^{2+}, Ni^{2+}, Cd^{2+}, and Pb^{2+} were determined using a Dionex 2000i Ion Chromatograph on filtered extracts of 5-mg samples of fine roots homogenized for 1 min in 1.0 mL 0.01 M HCl in a small conical glass homogenizer and rinsed with 2.0 mL 0.01 M HCl. Comparisons of 12 paired samples of fine roots, in which concentrations of Mn^{2+} in the 0.01 M HCl extracts determined by IC were compared to concentrations of Mn in the nitric/perchloric acid digests determined by AAS, indicated that the methods gave equivalent results as had been observed in wood analysis (Shortle and Bauch 1986). Al^{3+} was determined using a Dionex CS2 column eluted with a mixture of 0.01 M H_2SO_2 + 0.2 M $(NH_4)_2SO_4$ at a flow rate of 1.0 mL/min and detected as change in absorbance at 570 nm after postcolumn reaction with a pyrocatechol violet complex. Ca^{2+} was determined by using a Dionex CS3 column eluted with a mixture of 8 mM 2,3 - diaminopropionic acid + 48 mM HCl at a flow rate of 1.0 mL/min and detected by conductivity after suppression with 70 mM tetrabutyl ammonium hydroxide, at a flow rate of 5 mL/min. Divalent metals were determined in a single run using a Dionex CS5 column eluted with a mixture of 3 mM pyridine dicarboxylic acid at 4.3 mM LiOH + 2 mM NA_2SO_4 + 25 mM NaCl at a flow rate of 1.0 mL/min and detected as a change in absorbance at 520 nm after postcolumn reaction with complex PAR. All IC analyses were conducted at ambient temperature. Foliar analysis was done on triplicate 0.5-g samples of cleaned oven-dried (55°C), needles (1982 to 1984 needle years collected in 1985). K, Ca, Mg, and Mn were determined by AAS. The results are presented in Appendix B.

Results

The relative acidity of the humus layer in which most fine roots of spruce and fir were found was consistent in spruce-fir stands across northern New England (Table 1). The underlying mineral soil in which fewer fine roots of spruce and fir were found was slightly less acidic than the humus layer. Angiospermateous fine roots were more abundant in mineral soil than those of spruce and fir. The relative concentration of Al:Ca in the cortical apoplast of fine roots from the humus layer at Mount Abraham, a typical high-elevation site in Vermont, was distinctly different from all the other sites at decreasing elevation across northern New England (Table 2). At Mount Abraham, half the spruce in the forest canopy were dead and dying, whereas spruce trees appeared generally healthy at most other locations except Crawford Notch, where the largest red spruce had died, and Roach Pond, where the spruce budworm outbreak had been severe (Appendix A). The relative concentration of Al:Ca in the cortical apoplast of fine roots from the underlying mineral soil varied considerably among locations, but was greater than the humus layer at every location except Mount Abraham (Table 2). Al appeared to equal or exceed Ca in the cortex in mineral soil at most locations.

Actual Al:Ca molar ratios calculated from the quantitative determination of $Al3^{+}$ and Ca^{2+} ions in dry fine root tissue confirmed the EDXA patterns (Table 3). The fine root tissue in balsam fir and red spruce had a significantly greater Al:Ca ratio in the humus layer at Mount Abraham than at other locations. At Mount Abraham, two or more Al atoms were present in the cortex in humus for every Ca atom; at other locations, there were two or more Ca atoms for every Al atom in the cortical tissue. In mineral soil the ratio was about 1:1 and did not differ significantly among locations (Table 3).

Table 1.--Location, elevation, and relative acidity a of spruce-fir stands samples in November 1985

Location	Elevation	pH, H_2O[a]		pH, KCl	
		Humus	Mineral soil	Humus	Mineral soil
	m				
Mount Abraham, VT	1000	3.9-4.1	3.9-4.1	2.9-3.4	2.8-3.5
Crawford Notch, NH	800	3.5-4.0	4.0-4.2	2.5-3.3	3.1-3.9
Grafton Notch, ME	700	3.6-4.1	4.1-4.7	2.5-3.1	3.3-4.1
Hubbard Brook, NH	550	3.6-4.3	4.3-4.4	2.7-3.7	3.6-3.7
Bartlett, NH	400	3.2-4.3	4.2-4.9	3.0-3.3	3.9-4.5
Roach Pond, ME	400	4.0-4.2	4.3	3.1-3.5	3.3-3.5
Kossuth, ME	200	4.0-4.6	4.0-4.9	2.9-3.7	3.0-4.8
Beddington, ME	100	3.8-4.4	4.1-4.6	2.7-3.0	3.3-4.5

[a] Range of pH values based on 4 to 6 observations in the humus layer in which fine roots of spruce and fir are most abundant, and 2 to 4 observations in the mineral soil (A and B horizons) in which angiospermateous fine roots were more abundant than the sparse population of spruce and fir fine roots. Measurements were taken both in distilled, deionized water and with KCl added (Stienen et al. 1984).

Table 2.--Relative concentration of Al and Ca in the fine root cortical apoplast

Location	Relative concentration, counts[a]					
	Humus			Mineral		
	Al	Ca	Al:Ca	Al	Ca	Al:Ca
Mount Abraham, VT	2261 ± 74	861 ± 46	2.6	2734 ± 110	3132 ± 67	0.9
Crawford Notch, NH	442 ± 42	5317 ± 48	0.1	3296 ± 87	2417 ± 80	1.4
Grafton Notch, ME	350 ± 4	5533 ± 84	0.1	2768 ± 84	3424 ± 117	0.8
Hubbard Brook, NH	567 ± 3	5834 ± 71	0.1	1252 ± 40	3190 ± 96	0.4
Bartlett, NH	343 ± 4	3502 ± 107	0.1	(1500)	2984 ± 71	0.5
Roach Pond, ME	1669 ± 73	3634 ± 90	0.5	3436 ± 115	4099 ± 83	0.8
Kossuth, ME	446 ± 5	4453 ± 112	0.1	2865 ± 57	978 ± 32	2.9
Beddington, ME	11 ± 7	4922 ± 123	0.1	686 ± 13	1662 ± 61	0.4

[a] Mean and 95 percent confidence limits of 96 observations (eight measurements were made for each root in the 2nd to 4th row of primary root cortex apoplast on each of four trees, three roots per tree using EDXA; Al:Ca relative index value.

Further confirmation of the unique situation in the high-elevation spruce-fir stand was obtained by equilibrium soil-solution data from the two extreme locations, Mount Abraham and Beddington (Table 4). In the lower humus layer (Oa horizon) the molar Al:Ca ratio at Mount Abraham was 6 times greater than in Beddington, where red spruce trees were healthy. In the underlying mineral soil, the Al:Ca ratio varied greatly. In the decomposing litter above the humus layer, Ca was greater than Al at both locations.

A possible influence of increased input of N, but not S, was indicated at Mount Abraham relative to Beddington (Appendix C). Conductivity data indicated that the ionic strength of the soil solution at Mount Abraham was greater than at Beddington (Appendix C).

Discussion

The range of pH values observed in the humus and underlying mineral soil in the spruce-fir stands across northern New England was similar to those observed in many stands in Germany (Stienen et al. 1984). At around pH 4 Al, the third most abundant element

Table 3.--Molar ratio of Al:Ca in the whole fine root tissues

Species and location	Molar ratio of Al:Ca[a] Humus	Mineral soil
Balsam fir		
Mount Abraham, VT	1.7*	--
Grafton Notch, ME	0.3	--
Kossuth, ME	0.7	--
Beddington, ME	0.3	--
Red spruce		
Mount Abraham, VT	4.1*	3.1
Kossuth, ME	0.3	1.4
Beddington, ME	0.1	1.3
Howland, ME	0.3	1.0

[a] Ratio derived from determination of Al^{3+} concentrations in mol/g dry tissue using ion chromatography and Ca^{2+} concentrations using atomic absorption spectroscopy or ion chromatography. Mean molar ratios derived from 2 to 4 observations per location were compared by analysis of variance. Mean with asterisk differs significantly from those without.

Table 4.--Molar ratio of Al:Ca in the equilibrium soil solution of Mount Abraham, where spruce are dying, and at Beddington, where spruce are healthy[a]

Mount Abraham, VT Horizon	Al:Ca	Beddington, ME Horizon	Al:Ca
Oe	0.4	Oe	0.2
Oa	6.0	Oa	0.8
A	1.6	A	1.7
E	22.0	Bhs	8.5
		Bs	0.2

[a] Determinations made at the University of Gottingen on soil samples from the two extreme sites.

in the crust of the earth, is easily released into the soil solution where it can interact with the cations essential for plant growth. One of the major interactions is with Ca, the fifth most abundant element in spruce, fir and northern hardwood trees (H>C>O>>N>Ca >K>P>Mg, derived from Young and Carpenter 1967). The high Ca requirement for mature trees was recognized as a major difference between trees and crop plants (Rennie 1955) with a relatively low Ca requirement (H>C>O>>N>K>Mg>P>Ca, derived from Meyer et al. 1960).

Experiments with spruce seedings under various cultural conditions which the molar Al:Ca ratio was >1 indicated that this condition can affect the development of fine roots and shoots (Schier 1985; Stienen and Bauch 1987). Extracts of humus (organic soil horizons) collected from Camels Hump, Vermont (25 km north of Mount Abraham), where red spruce were dying, had a molar Al:Ca ratio of 13.0; those from Acadia National Park, Maine, (60 km south of Beddington), where red spruce appeared healthy, had a Al:Ca ratio of 1.2 (Taylor et al. 1986), (compared to Al:Ca for lower humus extracts, Table 4, Mount Abraham 6.0; Beddington, 0.8). When the humus layers from these locations were analyzed in an experiment with rain chemistry, mist chemistry, and ozone, soil type was the only treatment affecting both the above-ground and below-ground biomass of red spruce seedlings (Taylor et al. 1986). No treatment specific symptoms of visible needle injury were observed.

At Mount Moosilauke, New Hampshire, another high-elevation site, the Al:Ca ratio was >1 in percolating water and spring seepage (Cronan and Schofield 1979). In this case, the transport of Al into lakes and subsequent mortality of fish, not trees, was the matter of concern. The question then, as now, is whether the input of S and N emissions into the high-elevation forest ecosystem in particular, and over the entire region in general, can be contributing to the observed below-ground conditions, which, in turn, can effect above-ground parts of mature spruce and fir trees.

The input of strong anions into low-pH soils could cause the ionic imbalance indicated by the Al:Ca ratios in the mineral soil, as well as a Ca^{2+}: K^{+} antagonism on higher pH calcarious soil, which are not common in northern New England (Tomlinson 1987). The limiting effect of Al on tree development in the podzols of New England is not a new idea. Yellow birch (***Betula alleghaniensis*** Britton), a common associate in the spruce-fir stands observed across New England, develops a shallow root system on podzols. In most cases, the nutrient-adequate forest humus in which younger, smaller trees flourish was considered insufficient to compensate for the nutrient inadequacies of the mineral subsoil, especially when Al is added (Hoyle 1971).

At high-elevation sites, it appears that Al may now be affecting uptake in the humus, which is usually a safe place for fine root absorption. At Mount Abraham, where the Al:Ca ratio was >1 in the fine roots in the humus, forest damage was severe. The same is true for many severely damaged sites in Germany. At two locations, Al:Ca was >1 in the mineral soil, and the largest spruce (more than 200 years old) were dead at one of these, Crawford Notch. At the other location, Kossuth, the smaller younger spruce continued to look relatively healthy, but the trees retained fewer years of needles than other sites except for those where spruce budworm defoliation had been severe. Although acidic deposition may not have caused the acidity that allows Al to become available to interfere with Ca uptake, it may be accelerating the process. To counter this process, needles and branches of mature trees are being shed and will add Ca to the litter to be incorporated into the humus. The upper humus (Oe horizon of both Mount Abraham and Beddington had a favorable Al:Ca ratio (Table 4). When whole stands die at high elevation, even more Ca will become available to build a new humus, but this biological process takes time.

Processes taking place above ground are considered elsewhere (Shortle and Bauch 1986; Shortle and Smith 1988), but there seems to be a relationship among fine root uptake, a prolonged suppression of cambial activity, a reduction in sapwood basal area and in crown size, death of canopy trees, and internal damage of survivors. Existing soil conditions that threaten the spruce-fir forest include soil of approximately pH 4 accompanied by an Al:Ca ratio of ≥ 1. Where these conditions exist, forests are in jeopardy through the slow, steady input of strong anions of S and N. These anions contribute to the interference by the third most abundant element (Al) in the mineral soil on the uptake of the fifth most abundant element (Ca) incorporated into the tissues of the spruce-fir forest.

Acknowledgments

We thank the Office of International Cooperation and Development of the United States Department of Agriculture, and the Ministry of Food, Agriculture, and Foresty of the Federal Republic of Germany for supporting this research. We thank Prof. Dr. Josef Bauch for his continued support and advice and Mrs. Theresa Taylor for her typing of the manuscript.

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Appendix A

Brief stand description

Mount Abraham, VT: More than half of the spruce in the canopy were dead or dying, with the largest trees dying first. Fir were somewhat smaller than the spruce and were not as severely affected. Small spruce and fir appeared healthy. Years of needles retained: 1 to 2 declining spruce (some sprouts), 6 to 8 healthy spruce, 6 to 7 declining and healthy fir.

Crawford Notch, NH: Most of the largest spruce trees (diameter 35 cm) were dead or dying. Spruce beetle, mistletoes, and root rots were present in the stands. Some smaller spruce trees and fir trees (scattered through the stands), showed some thinning of the crown, but appeared generally healthy. Years of needles retained: 3 to 6 declining spruce, 6 to 10 healthy spruce; 6 to 8 declining and healthy fir.

Grafton Notch, ME: Commercial spruce-fir stand that had escaped defoliation by the spruce budworm. Spruce and fir crowns appeared generally healthy with some thinning crowns, but no mortality. Years of needles retained: 9 to 10 declining and healthy spruce and fir.

Hubbard Brook, NH: Small stand of spruce with scattered fir surrounded by northern hardwood stands. The spruce canopy looked generally healthy with a few thinning crowns. The canopy fir were mostly dead for several years, but the remaining few canopy fir appeared healthy. Regenerating fir seedlings were abundant and healthy. Years of needles retained: 6 to 8 declining and healthy spruce, 6 to 14 declining and healthy fir.

Bartlett, NH: Another spruce-fir stand similar to Hubbard Brook, but on a west-facing rather than east-facing slope. The canopy spruce appeared generally healthy, the canopy fir were mostly dead and infected with ***Armillaria mellea*** root rot. Regenerating fir seedlings were abundant and healthy. Years of needles retained: 8 to 15 declining and healthy spruce, 6 to 8 declining and healthy fir.

Roach Pond, ME: Commercial spruce-fir stand had been severely attacked by spruce budworm. Virtually all canopy fir were dead. However, spraying for the previous 5 years had allowed spruce to survive, though crowns showed evidence of the earlier severe attack. Years of needles retained: 3 to 5 declining spruce, 4 to 5 healthy spruce, 2 to 3 healthy and declining fir (sprouting).

Kossuth, ME: Commercial spruce-fir stand which showed recent evidence of mild budworm attack. The stands had been sprayed for 2 years and the crowns of spruce and fir were healthy with an occasional thinning crown. Years of needles retained: 6 to 8 declining and healthy spruce, 2 to 4 declining fir, 3 to 4 healthy fir.

Beddington, ME: Commercial stand similar to that at Kossuth. Canopy spruce and fir were uniformly healthy. Years of needles retained. 5 to 6 declining and healthy spruce and fir.

Appendix B

Concentrations of major cations in 1982-84 needles of spruce and fir trees cut at eight locations in November 1985 across northern New England

Location	Ion concentration, μmol/g dry tissue[a]							
	Spruce				Fir			
	Ca^{2+}	Mg^{2+}	Mn^{2+}	K^{+}	Ca^{2+}	Mg^{2+}	Mn^{2+}	K^{+}
Mount Abraham, VT	121	24	72	104	123	26	30	107
Crawford Notch, NH	142	24	39	113	313*	48	10	108
Hubbard Brook, NH	151	18	17*	100	241*	39	11	109
Bartlett, NH	185	35	57	89	260*	18	30	116
Grafton Notch, ME	147	46	22*	88	220*	33	20	96
Roach Pond, ME	122	41	45	102	--	--	--	--
Kossuth, ME	123	36	54	126	187	49	38	135
Beddington, ME	238*	38	42	98	241*	56*	17	132
Species Mean	153a	32a	44b	103a	226b	38a	22a	115a
1960's Mean[b]	105	24	21	125	170	34	12	120
1960's Range	65-209	19-56	12-27	97-151	81-269	28-48	3-21	36-563

[a] Ion concentration mean of two observations/location/species (one tree with healthy crown, one tree with declining crown; no significant differences observed between healthy and declining crowns in 2-way ANOVA). Asterisk indicates mean differs significantly from mean of Mount Abraham ($P < 0.05$, Dunnett's Test). Different letters next to species means indicates species means differ significantly ($P < 0.05$, F-Test).

[b] Mean and range of concentrations of major cations in foliage of spruce and fir seedlings and saplings growing in Maine in the early 1960's (Young and Carpenter 1962).

Appendix C

Equilibrium soil solution analysis of sulfur, nitrogen, and conductivity at Mount Abraham and Beddington

Mount Abraham				Beddington			
Horizon	S(mM)	N(mM)[a]	μS/cm³	Horizon	S(mM)	N(mM)[a]	μS/cm³
Oa	0.29	1.16	256	Oa	0.29	0.41	193
A	0.41	1.00	247	A	0.38	0.42	122
E	0.24	1.23	171	Bhs	0.07	0.29	87

[a] >96 percent ammonia nitrogen.

"Air Pollution and Forest Decline" Research Program and Strategy of the State of North Rhine-Westfalia.

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Introduction

Since the beginning of the 1970's, novel forest decline has been observed in Southern Germany, especially on silver fir *(Abies alba)*, later also on Norway spruce *(Picea abies)* and meanwhile has increased to an alarming extent. Even though the percentage of progression is decreasing annually according to the latest inventories, novel forest decline is still present. Because forests of Southern Germany were the first to be affected, early studies were focused on this region to access the extent and to evaluate possible causes.

Since 1982, novel forest decline has also been observed in North Rhine-Westfalia, and the state government decided immediately to develop a strategy and research program to cope with these problems. Within the "Environmental Protection Program" of 1983 a special campaign for forest protection has been created which includes special measures for the preservation of the forest, focussing on the reduction of $S0_2$- emissions, introduction of new filter technologies, economizing energy as well as intensifying research work, and the establishment of silvicultural relief actions for the damaged forest as a first aid (Fertilizer programs or special bark beetle control measures).

The first program was followed by a second one in 1984 in order to coordinate the methodology for surveying the extent and intensity of novel forest decline with other states of the FRG, resulting in inventories, which since then were based in random sample plots with single tree evaluation. Furthermore, research projects were started to elucidate possible cause-effect relationships. From this, the current research program "Air pollution and Forest Decline" was developed in 1985. The name already expresses the general opinion that the air pollution factor is anticipated to be a major cause for the phenomena observed. The questions to be answered, however, are of complex nature, since anthropogenic stress factors interfere with natural stress factors, and the evaluation of cause-effect relationships require the cooperation of various scientific disciplines.

In order to guarantee maximum effectiveness of research involved, a coordinating and supervising board was established and located at the LIS since 1985 on behalf of the Ministry of Environmental Affairs of North Rhine-Westfalia (MURL). Apart from the actual coordination of research, federal research porgrams are also considered in the state of NRW, before decisions are made on the research project to be supported. This will avoid duplication of effort of independent research teams. Emphasis is also put on the possibility to support existing as well as finished projects by complementary research and to open new aspects of research.

Fulfillment of the research program is generally carried out by the procedure, presented in figure 1. When proposing a research project to the Ministry (MURL), the question of deserving promotion is decided first on the research objective of the project, following a formal criteria catalogue. Therefore scientists of various disciplines have been brought together to constitute an advisory committee for scientific evaluation of the proposal. After careful consideration of the criteria and, assuming the MURL follows the positive vote of the advisory committee, the application of the research project is handed over to our institute and from now on attended by the LIS. Right now there are more than 30 projects sponsored by the MURL. They are divided into the fields (A) Preliminary Methodical Studies, (B) Realization of Specific Research Objects and (C) Deduction of Generally Valid Conclusions and the Evaluation of Generalizing Models. These fields are documented in the so-called "Research Plan" which accompanies the research program.

The major points of the research fields, where the research projects are integrated, are the following:

A. Preliminary Methodical Studies

1. Methods to assess forest injury and define their extent
2. Development of methods for differential diagnosis of the novel forest decline
3. Assessment of the dynamics of the soil-chemistry parameter
4. Methods to assess the spectrum of effects of dry and wet deposition on plants
5. Development and adaptation of measuring techniques to study transport phenomena of air pollutants as well as their reactions within the atmosphere
6. Preliminary methodical studies to reduce and avoid forest decline

B. Realization of Specific Research Objects

1. Observation, description and assessment of the forest decline situation in Northrhine-Westfalia.
2. Definiation of the ambient air pollution situation including dry and wet deposition in various forest stands of North Rhine-Westfalia
3. Definition of air pollution burden (dry and wet) on single trees and single forest stands in general as well as mineral leaching processes
4. Definition of primary plant reactions as a result of air pollution impact.
5. Definition of the resulting effects of the primary reactions mentioned under B4, or the modification of

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these primary reactions by other environmental factors such as soil climate and pathogens.

6. Definition of the primary influence of the air pollutants on the soil and subsequent results for the plant
7. Definition of the emission-, dispersion and transport phenomena of air pollutants

C. Deduction of Generally Valid Conclusions and the Evaluation of Generalizing Models
   1. Passive protective measures
   2. Planning and technological measures
   3. Political and administrative instruments to reduce decline or eliminate injury causes

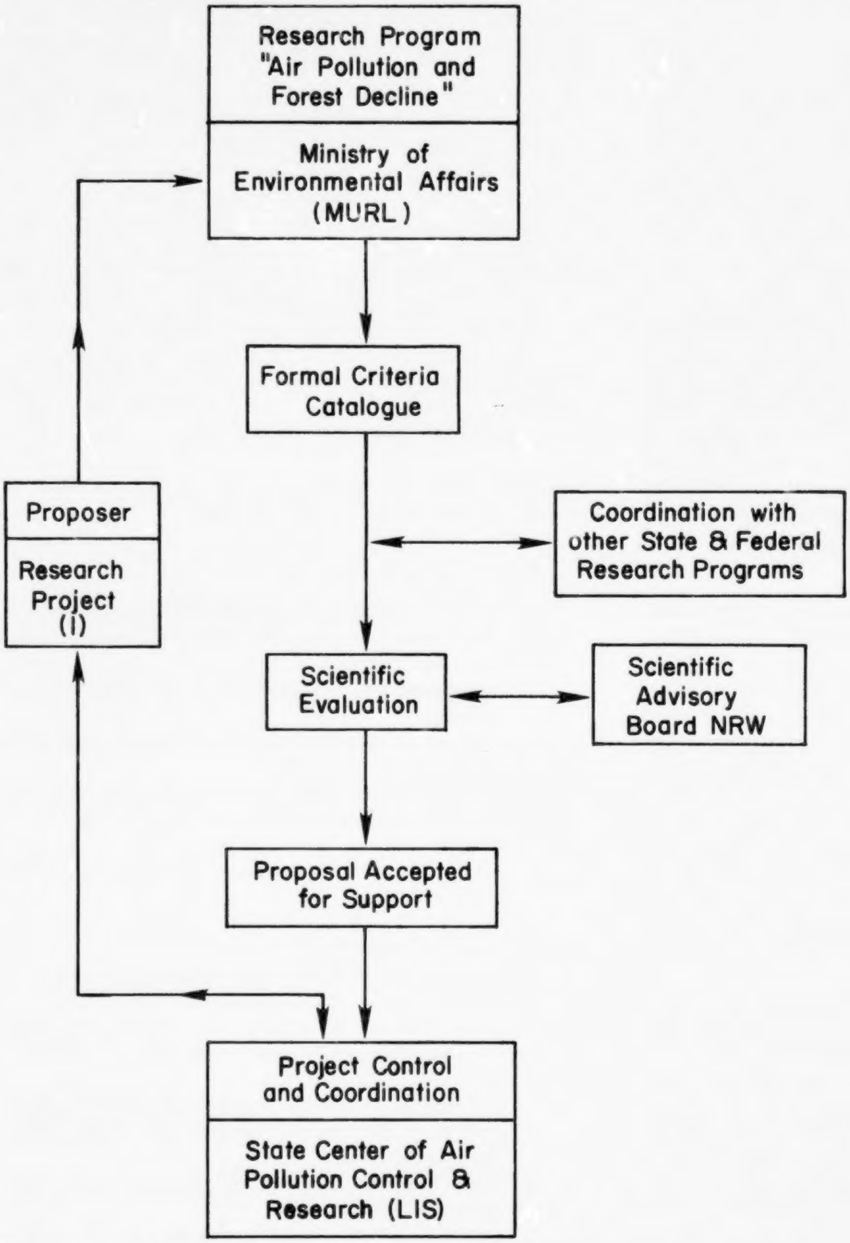

Research Program
"Air Pollution and Forest Decline"
Ministry of Environmental Affairs (MURL)
Formal Criteria Catalogue
Proposer
Research Project (I)
Coordination with other State & Federal Research Programs
Scientific Evaluation
Scientific Advisory Board NRW
Proposal Accepted for Support
Project Control and Coordination
State Center of Air Pollution Control & Research (LIS)

Figure 1.--Procedure of fulfillment of the research program.

As far as the first complex (A) is concerned, there is only a limited number of proposals right now. In this sector much research work still has to be done in order to provide the fundamentals for the realization of the specific research work mentioned in part (B) and also for the technologies and administrative measures specified in part (C). The majority of studies relates to the topics B3 and B4 dealing with the characterization of the ambient pollution burden and its direct effect on the plants. Part (C) comprises research projects dealing with protection measures against the air pollution of technologies to reduce emissions. Each project is documented in the research plan with an abstract.

The Idea of The Research Plan

The primary objectives of the research plan are:

- to give a summary of the existing knowledge of the research on forest decline,
- to provide basic data to the scientist as basis for his research work,
- to construct a complete chain of evidence for cause-effect relationships of novel forest decline by pretending specific research questions
- to provide some control measures for quality assurance of the projects
- and to document all current and future research projects

These requirements are realized as far as possible within the scope of the research plan. An outline of its content and structure is presented in the following:

1. An introductory part (chapter 1) lists all available data of specific site factors for a given location, especially soil conditions, meteorological as well as general silvicultural data of the forest research stands in NRW. They are followed by statements on the progress of forest decline and detailed description of the ambient air pollution situation in North Rhine-Westfalia. For example, Fig. 2 gives some meteorological parameters of the last 15 years of a typical highland meteorological station in NRW, where the frequency of dry and warm summers has been abnormally high during this period. Another example of the introductary information demonstrates the different air pollution situation between forest sites in remote areas and the Rhine-Ruhr area (see figure 3).

   While the classical air pollutants are generally lower in the remote areas, ozone concentrations exceed those of the Ruhr area by a factor of more than 2. Average monthly summer concentrations are well above 100 $\mu g/m3$. Although peak concentrations are higher in the Ruhr area, the ozone-dose at the remote site is much higher, due to more or less constant 0_3 values over 24 hours. This is explained by the pronounced lack of NO in remote areas and the slow breakdown of O_3 associated with it. The main characteristic is that contrary to the other components, ozone does not differ so much in the peak values but in the average values between the "source"- and "remote" areas.

2. The next part of the plan (chapter 2) documents the phenotype of forest damages, that is the definition of tree decline type taken as basis for the research objective (tree species, symptomatology and its classification to the entirety of novel forest decline considering temporal and spatial development). As an example the description of symptoms of Norway spruce as the main damaged forest tree in Northrhine-Westfalia is given:

   Symptomatology of Norway spruce decline shows great variation, reaching from needle loss without preceding discolouration to distinct chlorosis with or without needle cast. Two kinds of symptoms seem to be of outstanding importance - the yellowing of needles and thinning of the crown. From the point of spatial distribution and novelty of appearance the yellowing of needles seems to be the more specific kind of symptom while the thinning of crowns reflects more or less unspecific symptoms, commonly associated with climatic stress like the example of abnormal frequency of hot and dry summers during the last decade. The yellowing of needles is clearly related to deficiency of nutrients, especially cations like magnesium, calcium, zinc, potassium and maganese in combination with radiation. Severity of chlorosis increases with elevation as well as deficiency of these nutrients in soil. The magnesium deficiency-type, as the most important one, shows chlorophyll deficiencies especially in needles of older age classes.

   The youngest needle generation remains green until late fall and gradually turns yellow during winter and beginning spring, thus the new needle generation gives the appearance of a green fringe. High $Mg++$ - concentrations are always found in youngest needles and are gradually lowered in the older generations, as shown in Fig 4.

3. In the third part of the plan (chapter 3), a generally valid research strategy is presented to examine the presumed causes of the decline funneling research in the direction which is best suited for the solution of the problem by use of critical path methods. A scheme has been created, demonstrating the principally possible pathways of impact on the vitality of forest trees - the most probable one at present (figure 5).

   The most important pathways of the impact of air pollutants on the forest tree (broad arrows) are:

   a. direct effect on above-ground parts of trees
   b. indirect effect via the soil and its impact on plants by accumulation processes of dry and wet deposition of air pollutants
   c. secondary penetration of the soil by air pollutants, deposited on above-ground plant parts washed out during precipitation.

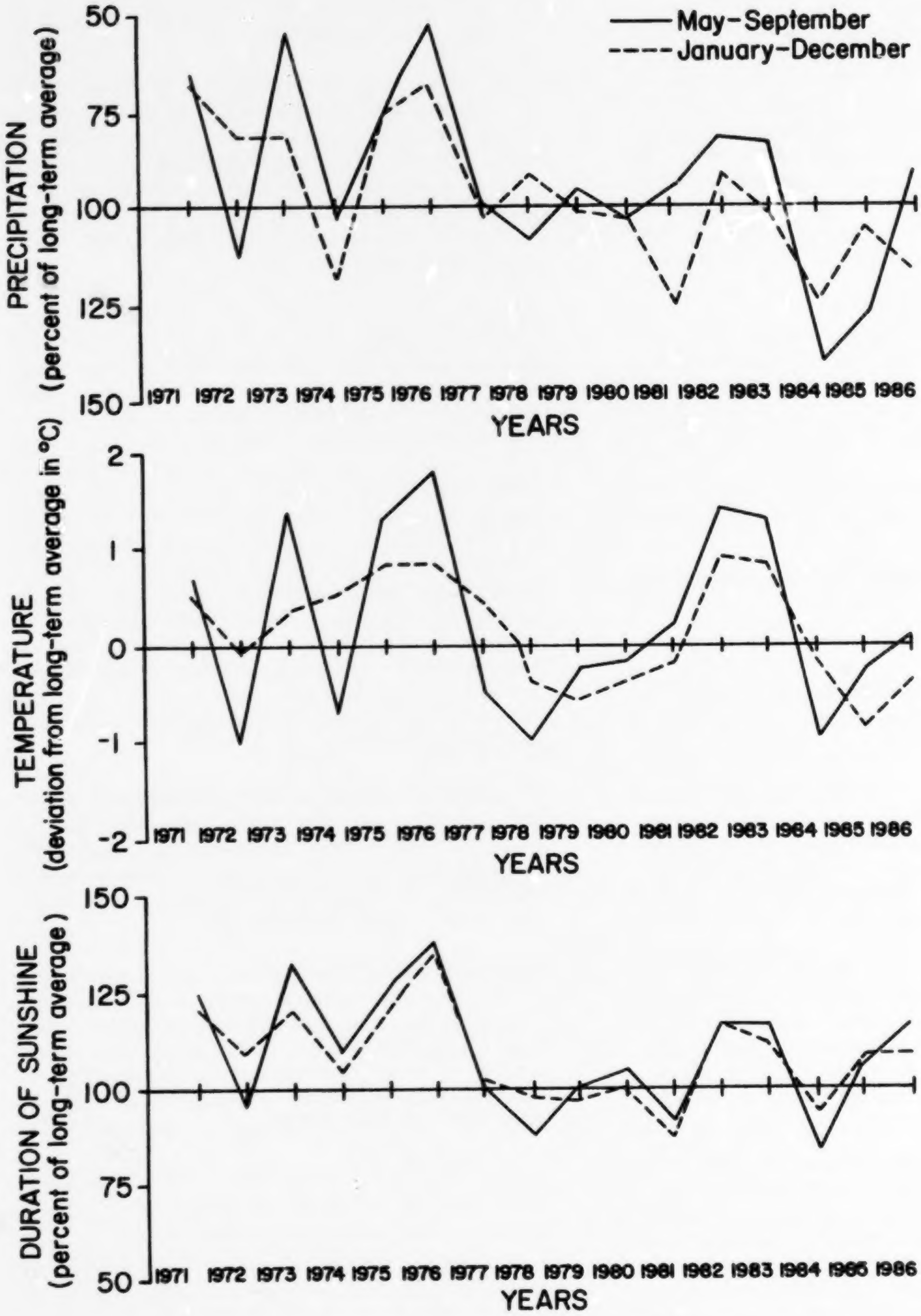


Figure 2.--Variation of temperature, rainfall and solar radiation within the last 15 years at the meteorological station in Lüdenscheid (Sauerland mountains in North Rhine-Westfalia).

The effects of pathogens, climate and soil itself as damaging agents are seen as background factors (Small arrows) in this diagram. The broken small lines mean internal forest dynamics.

The integration of the research projects within an over-lying concept ensures that research results are of relevant contribution to solve the general problem. In order to get qualified results of each project - which represents some kind of quality assurance - the following conditions must be fulfilled;

a. it must be possible to relate specific symptoms of injury to the causal factor in question

b. temporal development of injury must coincide with temporal development of the causal factor in question including accumulation effects and delayed action of the factor

c. spatial distribution of injury must largely coincide with spatial distribution of the factor in question

Furthermore, for quality assurance research is required to orientate on actual symptomatology, since the causal agent in question can only be considered relevant, when simulated under defined conditions like in chamber experiments etc. At last, research has to be carried out under the utmost comparability of methods, including comparable technical equipment as well as plant material and other methodological procedures. In order to guarantee that the studies are carried out under the same conditions, a total of eight regional forest research sites have been selected in NRW as research centers.

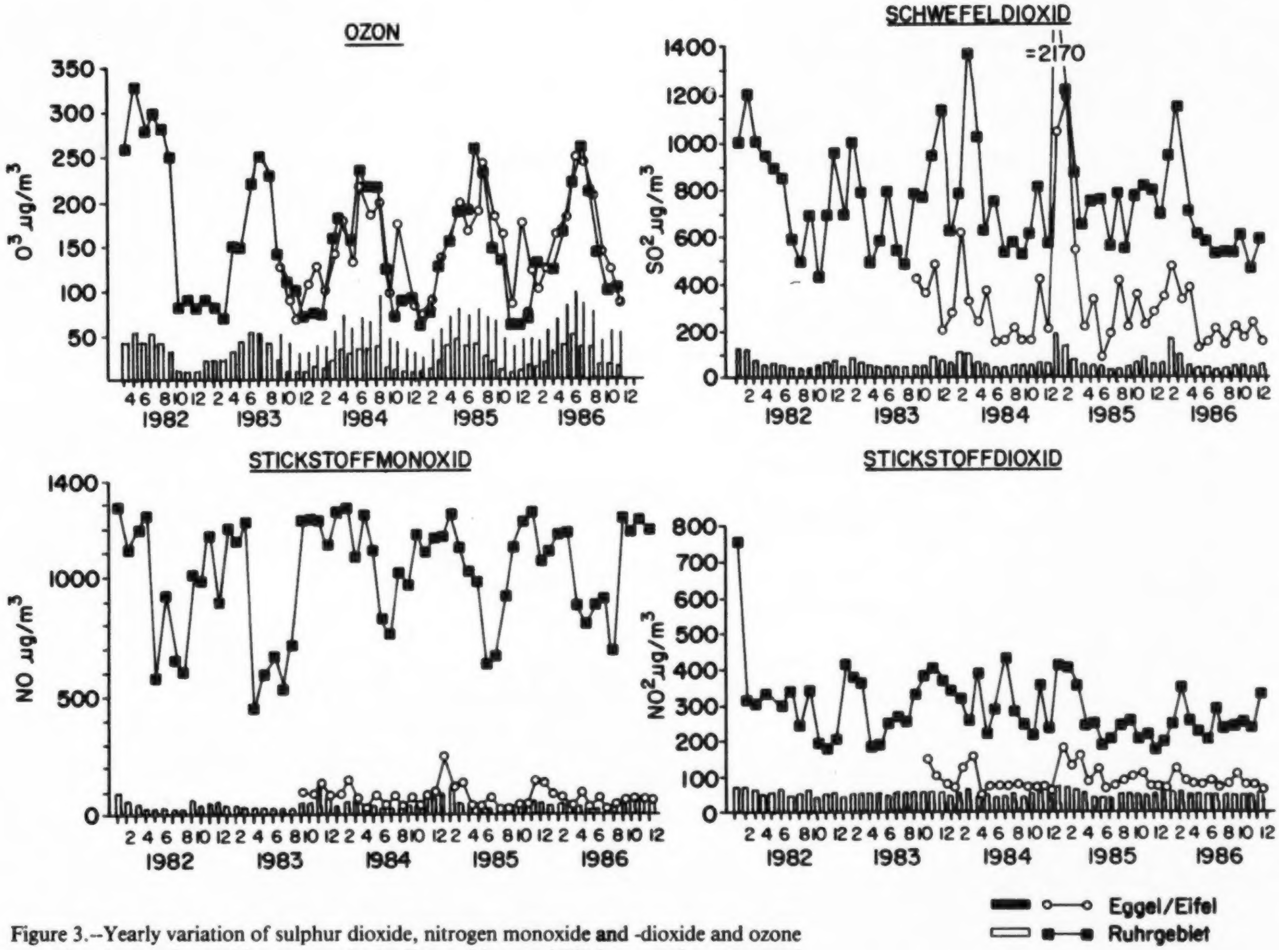


Figure 3.--Yearly variation of sulphur dioxide, nitrogen monoxide and -dioxide and ozone as peak values and monthly averages in the Eggegebirge and Eifel mountains compared with the Rhine-Ruhr urban area.

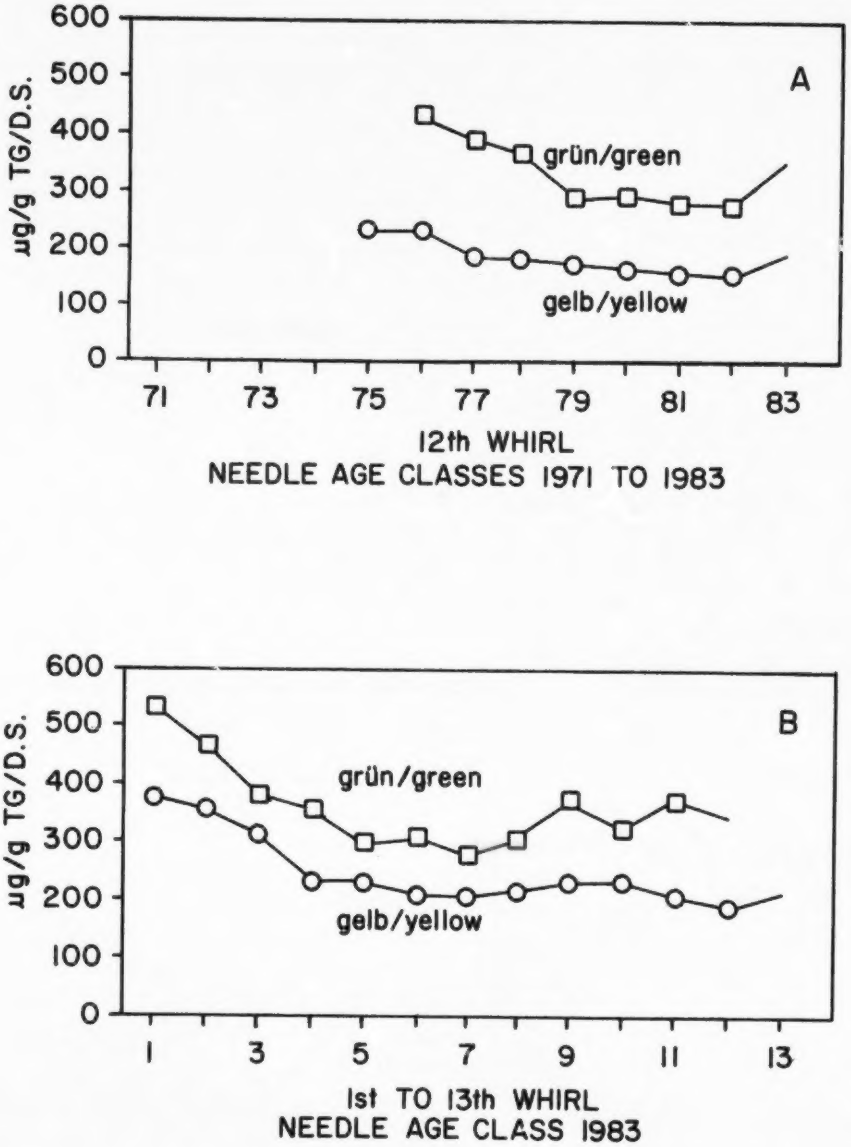


Figure 4.--Magnesium content of needles in different years (A) 12th whorl, and (B) whorl 1 to 13.

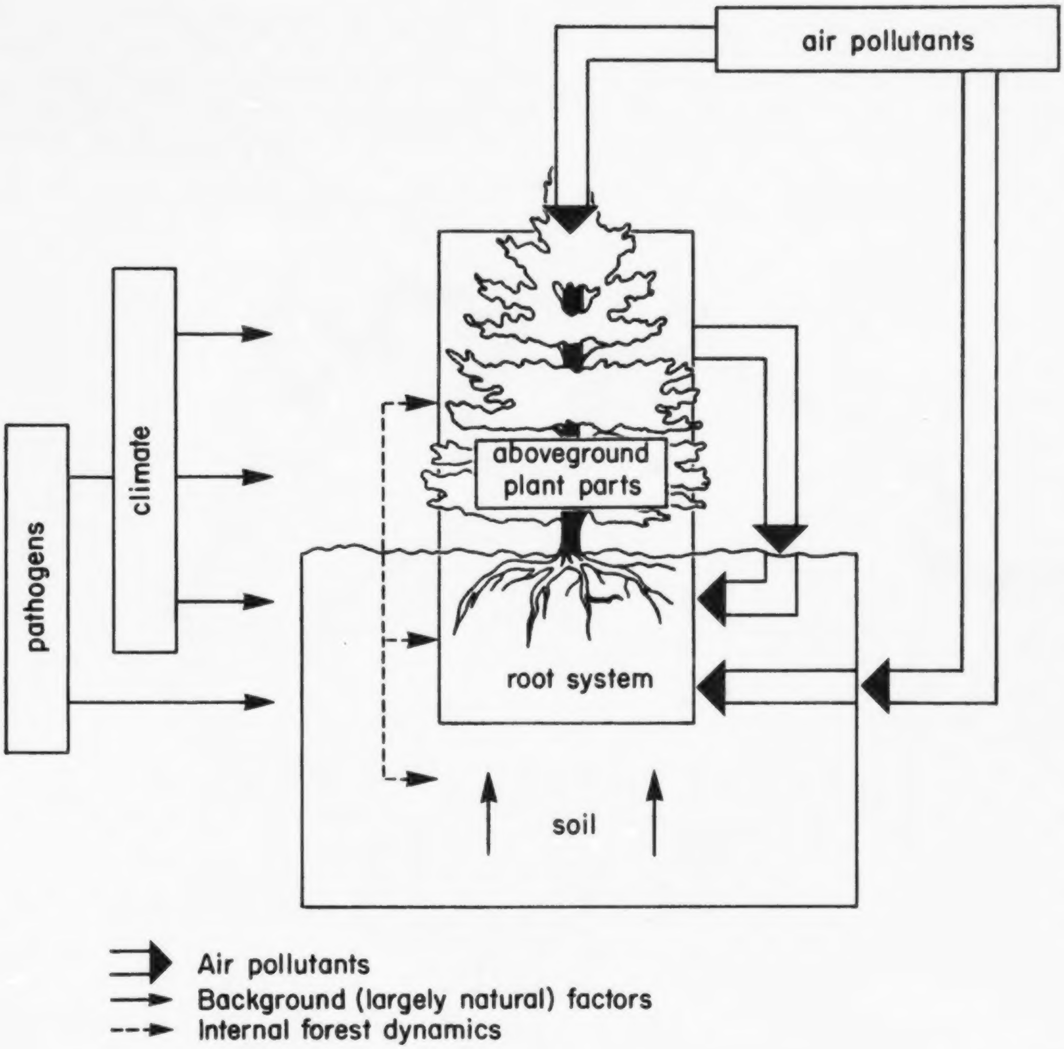
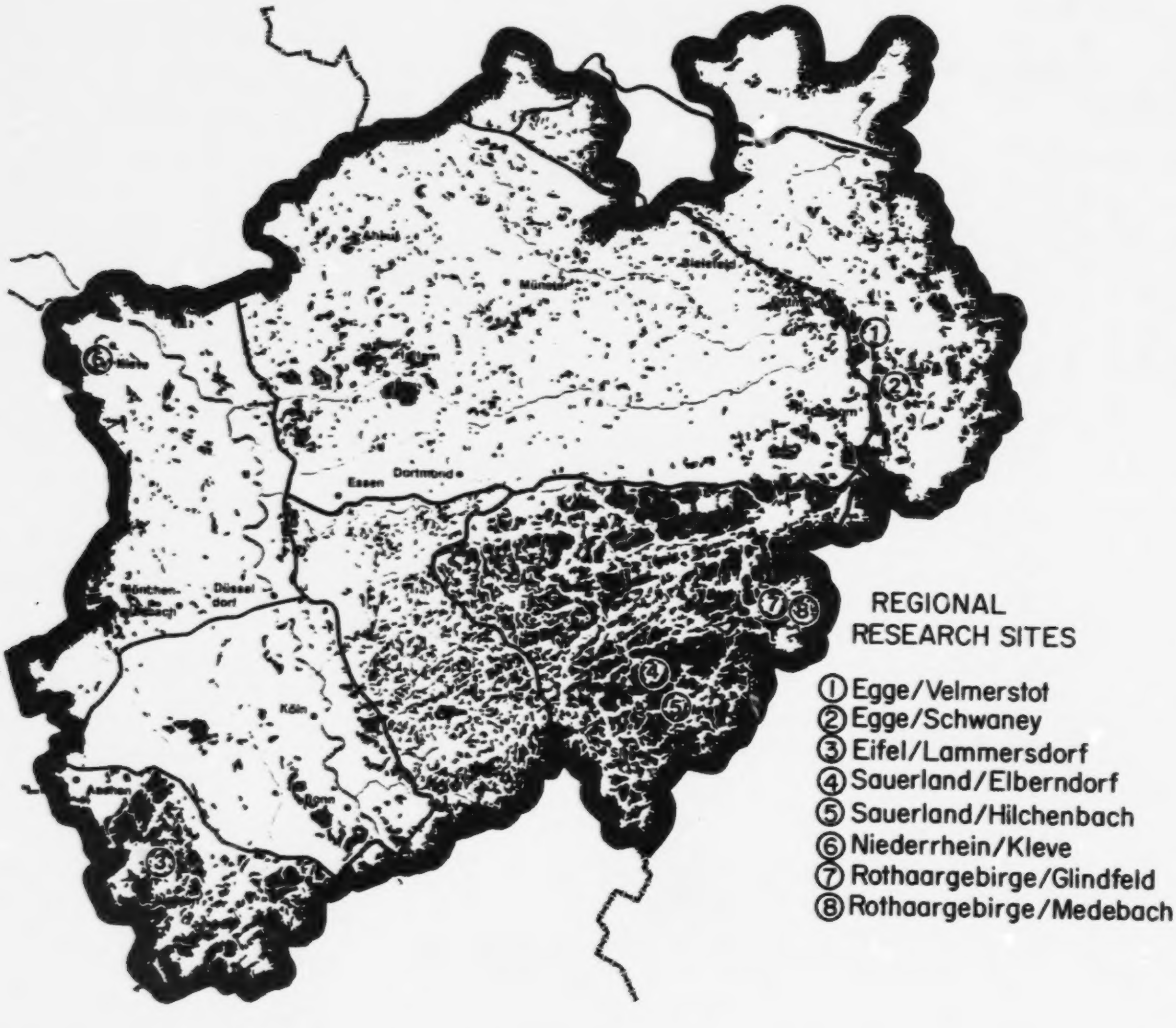

air pollutants
pathogens
climate
aboveground plant parts
root system
soil
Air pollutants
Background (largely natural) factors
Internal forest dynamics

Figure 5.--Scheme for possible pathways of impact on the vitality of forest trees.

4. The description of the regional forest research sites of North Rhine Westfalia is given in chapter 4 of the research plan. The most important one is site (1) on the map (figure 6), called "Eggegebirge/Velmerstot". In this region, the most significant decline has been observed in North Rhine-Westfalia, which can probably be explained by the exposed location of this site to the agglomeration of the industrial Ruhr area, 150 km south-west. Since the Egge-mountains are the first barrier behind the Ruhr area in a north-easterly direction, impact of air pollutants is especially pronounced.



REGIONAL RESEARCH SITES
① Egge/Velmerstot
② Egge/Schwaney
③ Eifel/Lammersdorf
④ Sauerland/Elberndorf
⑤ Sauerland/Hilchenbach
⑥ Niederrhein/Kleve
⑦ Rothaargebirge/Glindfeld
⑧ Rothaargebirge/Medebach
Kleve
Münster
Bielefeld
Essen
Dortmund
Mönchen-gladbach
Düssel dorf
Köln
Bonn
Aachen

Reproduced from best available copy.

Figure 6.--The regional research sites and forest distribution in North Rhine-Westfalia.

According to the "Forest Injury Inventory" made during the last few years, the research sites show a clear gradient. While those in the Eggegebirge (1) and (2) are most affected, research sites at the Rothaargebirge (7) and (8) are least affected. As pointed out earlier, comparable sampling sites are one necessary prerequisite for an integrated research activity. This was realized by the set-up of two scaffolds (22 m height) at site (1) and (7), linking as many as 26 trees together, where samples of specific trees, and specific branches at defined whorls can be obtained throughout the year (figure 7). There is also the possibility to execute physiological experiments directly within the crown of trees in representative age. Of further advantage is the structure of two platforms at different heights, also allowing research on shaded parts of the tree. For air quality control, the LIS operates 65 monitoring stations within the TEMES network of NRW, registering automatically ambient air concentrations of SO_2, NO_2, NO_3, CO_2, CO, suspended particles as well as meteorological data. Three of these stations are located in forested areas in NRW like the Eifel, Egge- and Rothaar-mountains and continuous monitoring has been carried out since 1983.

Heavy metals and some polycyclic aromatic hydrocarbons, are measured discontinuously. Wet and dry deposition is measured by common bulk-sampling procedures in the open field as well as within the closed stand by the LOELF stations (State Institute for Ecology, Land-use Planning and Forestry) and in a more detailed way within the MEXFO program (Monitoring and Experimental Station in the Forest). In addition to air samples, samples of rain, fog and soil water are analyzed at 5 sampling points in- and outside of the forest stand and at the forest fringe.

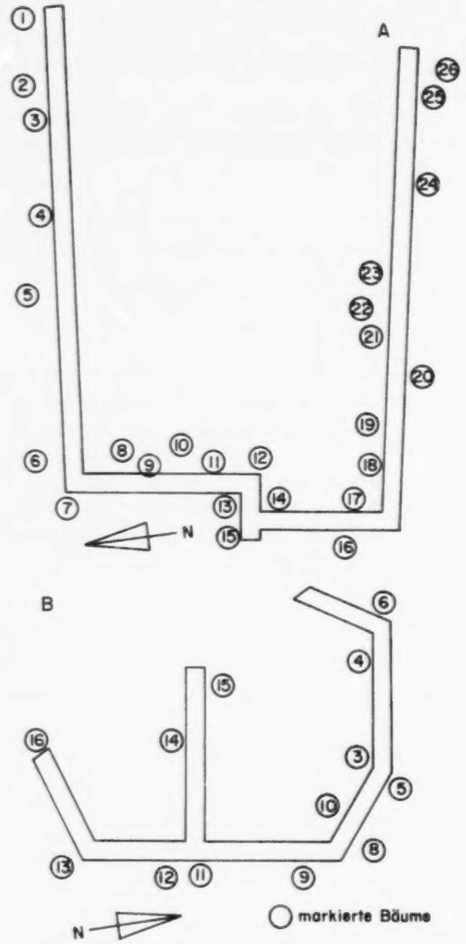


Figure 7.--The ground plan of the scaffolds (A) scaffold at forest research site (1) (length 70 m) Eggegebirge/Velmerstot, (B) scaffold at forest research site (7) (length 45 m) Rothaargebirge/Glindfeld.)

Furthermore, chapter four of the research plan consists of a summary of the presumed causes for novel forest decline at the present state of knowledge. The factors are listed briefly as follows:

a. Long term trend: acidification of soil, coinciding with nutrient deficiency as well as the general increase of ambient ozone in the atmosphere (Schavins, Black forest, monthly means over 180 ug/m3)

b. Short term trend: high peaks of ozone concentrations in the last few years during summer months

c. Long range variation: increased impact of ozone at the higher elevations as well as high frequency of fog exposure in these regions

d. Small range variation: mostly geogenic formed conditions of soils

e. Climatic conditions as a synchronizing factor.

As a base of discussion a diagram showing the effects of exposure to ozone in combination with acid rain or fog is presented (see figure 5 in Prinz, this symposium). As a conclusion of experimental results at the LIS this figure represents in a more detailed form, the most likely cause-effect relationship for novel forest decline.

The research plan should always represent the actual state of knowledge. It will be up-dated as soon as new findings and convincing results represent a more reliable hypothesis of the causes of forest damage. The basic data will be up-dated annually as well as the documentation of the research projects.

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